GIOTTO

ASTRONOMY

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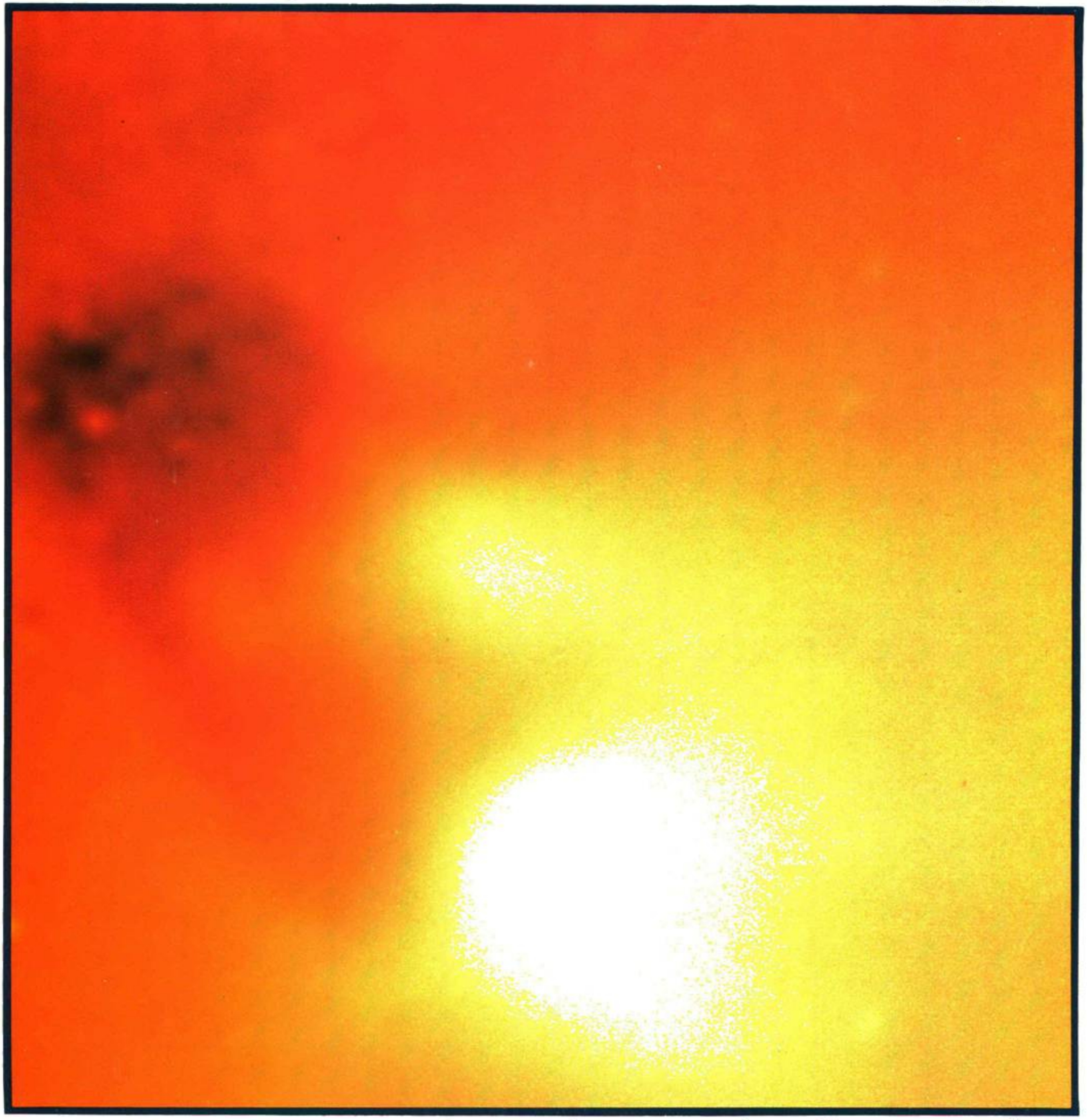
Comet Halley Revealed:

Giotto's Fantastic Fly-Through

Don't Miss Magnificent Mars



Giotto Pictures of Halley's Nucleus

MEADE SUPER WIDE ANGLE
Super Plössls
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Meade®:
Ultra Wide Angles
Air-Spaced Barlows

First in Eyepieces too.

A New World Standard in Professional Optics for the Serious Amateur.

In 1984, Meade engineers set out to design the finest eyepieces and Barlow lenses—bar none—ever made available for modern telescopes. Specifications called for an unprecedented order of sophistication. Computer optimized design. Special low dispersion glasses (some not even available until recently). And the very latest in coatings technology. Not surprisingly, the resulting Meade Series 4000 is nothing less than a new performance standard in professional optics. The eyepieces and Barlows you would expect from the World's leading manufacturer of astronomical telescopes for the serious amateur.

Design Specifications: Meade Series 4000 eyepieces yield the widest possible fields of view, consistent with pinpoint edge-of-field sharpness and long eye relief, and yet with extremely low astigmatism, spherical aberration, and off-axis color. Incorporating 7-layer multi-coatings and edge-blackened optics for optimal image contrast, these sophisticated 5- to 8-element designs permit levels of optical corrections virtually impossible to achieve with eyepieces of fewer elements. The polished chromed-brass barrels are threaded for standard filters, and, where practical (see table), eyepieces and both Barlow lenses are parfocal, allowing eyepiece interchangeability without refocusing.

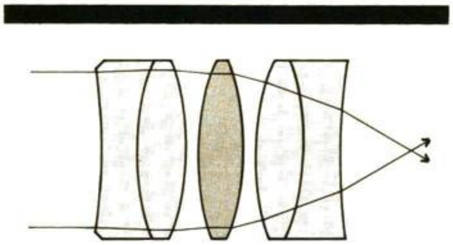
Eyepiece Groups: Eighteen focal lengths in the three Series 4000 eyepiece groups permit precisely the right eyepiece for any application. Whether your telescope is an f/4 Newtonian, an f/10 Schmidt-Cassegrain, or an f/16 refractor, its performance will benefit by using these incredible oculars:

Super Plössls: With 5 optical elements rather than the traditional 4, Meade Super Plössls provide a 40% improvement in corrections for chromatic aberration and edge-distortions over any other premium Plössls. Best for general observing at moderate cost, the Super Plössl eyepieces are perfect optical complements for the Series 4000 air-spaced Barlows, below. Try the 56mm on your 8" Schmidt-Cassegrain for an actual field of over 1.4° at 36X!

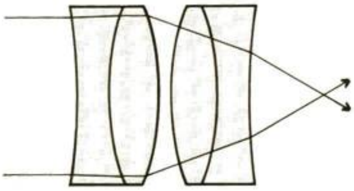
Super Wide Angles: These 6-element eyepieces, with their 67° fields, offer exquisite wide-angle images at low to medium powers, ideal for star fields, galaxies, and other deep-space phenomena. Focal lengths with 1¼" barrels yield extremely high-resolution, high-power lunar and planetary images when combined with one of the Series 4000 Barlows.

Ultra Wide Angles: The ultimate in modern eyepieces, Meade 8-element Ultra Wide Angles permit extreme image fidelity and sharpness over an amazing 84° apparent field: for moderate to high power applications, no other eyepieces come close. A magnificent optical match with Schmidt-Cassegrains and fast Newtonians.

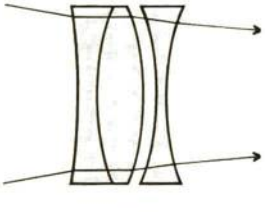
Series 4000 Barlow Lenses: The most sophisticated Barlows ever developed for commercial telescopes, these 2X and 2.8X Telenegative Amplifiers include 3-element, air-spaced, multi-coated optics, unmatched in image resolution and color correction. Both models optically complement the Series 4000 eyepieces, while significantly enhancing the performance of other eyepieces as well.



Meade 5-element Super Plössl design: the central lens element enables significant reductions in chromatic aberration and edge-distortions over other premium Plössl designs.



Other premium Plössls: include only the traditional 4-elements.



Meade Series 4000 Barlows: 3 elements, air-spaced, instead of the standard 2 non-air-spaced elements.

Series 4000 Eyepieces and Barlows

Super Plössls (5-elements)	APPARENT FIELD	BARREL DIA.	PARFOCAL
6.4mm	52°	1¼"	Yes
9.7mm	52°	1¼"	Yes
12.4mm	52°	1¼"	Yes
15mm	52°	1¼"	Yes
20mm	52°	1¼"	Yes
26mm	52°	1¼"	Yes
32mm	52°	1¼"	Yes
40mm	44°	1¼"	No
56mm	52°	2"	No
Super Wide Angles (6-elements)			
13.8mm	67°	1¼"	Yes
18mm	67°	1¼"	Yes
24.5mm	67°	1¼"	Yes
32mm	67°	2"	No
40mm	67°	2"	No
Ultra Wide Angles (8-elements)			
4.7mm	84°	1¼"	Yes
6.7mm	84°	1¼"	Yes
8.8mm	84°	1¼" & 2"	Yes
14mm	84°	1¼" & 2"	No
Barlow Lenses (3-elements, air-spaced)			
#140 2X Telenegative Amplifier		1¼"	Yes
#142 2.8X Telenegative Amplifier		1¼"	Yes

Meade 2" Mirror Diagonal: For attachment to Schmidt-Cassegrain telescopes, the 2" Mirror Diagonal permits use of Series 4000 eyepieces with 2" barrels. The 1/10-wave-flat Pyrex mirror, manufactured at the Meade Costa Mesa optical facility, is multi-coated with enhanced aluminum for maximum reflectance. An adapter for 1¼" eyepieces is included.

Where To Buy: Meade Series 4000 eyepieces and Barlows are available from over 600 authorized Meade dealers in the U.S.A. and Canada. Call us toll-free (see below) for your nearest dealer.

Prices: Notwithstanding their performance standards and optical sophistication, Meade Series 4000 eyepieces and Barlows are priced very competitively with other premium oculars and Barlows.

Warranty: All Series 4000 systems are covered by the Meade Limited Lifetime Warranty—the most extensive in the industry. See the Meade catalog for details.

New 1986 Meade General Catalog 86-C: $3.00

Just-published, the new Meade 1986 General Catalog includes complete information on the full range of Meade astronomical products, along with a supplement on **"How To Choose Your Eyepieces."** Send $3.00 for your copy.

U.S. and Canada Dealer Locations & Assistance

For your nearest Meade dealer location, or for free telescope information and assistance, call Meade Instruments **toll-free** from anywhere in the continental U.S.A., (except Calif.):

1-800-854-7485

From all other areas, including California, call direct: **(714) 556-2291**

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Cover: On March 14, when it was 18,000 kilometers from the nucleus, ESA's Giotto spacecraft camera returned this dramatic image of the 15-kilometer-long nucleus of Halley's Comet spewing jets of dust toward the Sun. Copyright © 1986 by the Max-Planck-Institut für Aeronomie.

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GIOTTO

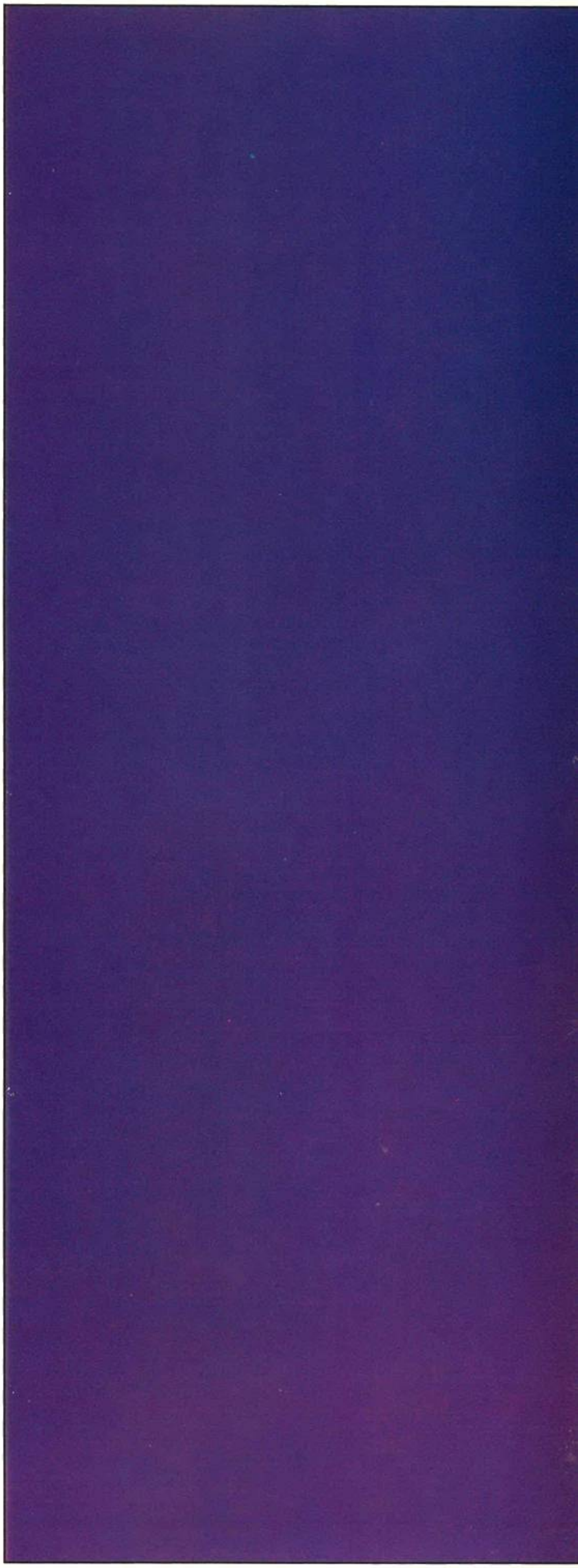
Encounters Comet Halley

by Richard Berry

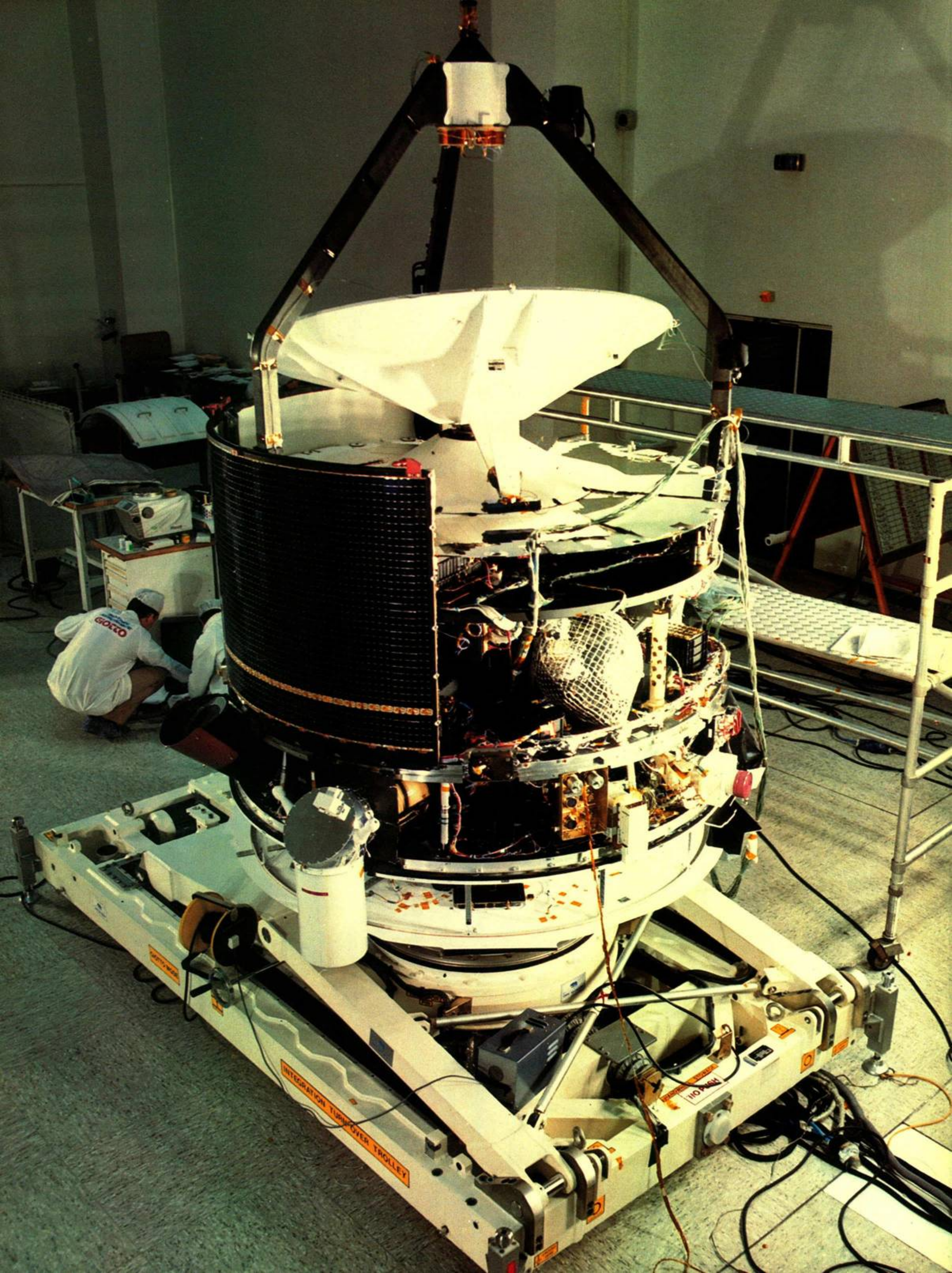
At 8:23:16 a.m. local time on July 2, 1985, the Ariane 1 rocket's main engines ignited and the vehicle lifted off. Atop the rocket "stack" was Europe's Giotto space probe. Thirteen minutes after leaving pad ELA 1 at the Arianespace launch site in Kourou, French Guiana, the 960-kilogram spacecraft began the first of three circuits of Earth in an elliptical transfer orbit. At the third apogee, Giotto's MAGE-1 SB rocket motor fired, boosting the probe into a Sun-centered orbit that, eight months later, would intersect the path of Halley's Comet.

Unlike the joint ESA/NASA International Cometary Explorer mission to Comet Giacobini-Zinner last year (see "ICE: Mission to Comet Giacobini-Zinner," December 1985), the Giotto probe was designed to answer scientific questions about comets. Riding aboard the 1.6-meter high by 1.8-meter diameter cylinder were a high-resolution camera to send close-up images of the mysterious nucleus back to Earth, mass spectrometers to probe the chemical compositions of cometary gases, a variety of sensors to detect fine solid material such as comet dust, and an array of fields and particles instruments to measure the ghostly flows of ions, the hot plasmas, and the twisted magnetic environment of the comet. At the rear of the spacecraft, a 1.6-meter parabolic antenna pointed toward Earth. With spectacular bravado, Giotto was targeted to penetrate deep into the coma of Halley's Comet to sample the raw stuff boiling into space, passing within a mere 500 kilometers of the nucleus itself.

Of course such a mission was risky, but the scientific stakes were high. A successful mission would answer vital questions about the nature of comets, the nature of the nucleus, its composition, and how comets interact with the interplanetary medium. But flying within a cosmic stone's throw of the nucleus at the breathtaking relative velocity of 68.4 kilometers per second (fifty times the speed of a rifle bullet) seemed like sheer madness. Giotto was protected, to be sure, with twin dust shields, but striking even a tiny grain of rock could destroy the probe or send it spinning wildly out of control. Depending on who was making the estimate, there were perhaps nine chances out of ten that Giotto would survive. Although dubbed a kamikaze mission, the Giotto mission was really more like a game of Russian roulette with the probability



Giotto's Multicolor Camera scanned the potato-shaped nucleus of Halley's Comet from a distance of 20,000 kilometers, sending this image back to Earth. Two dust jets stream from the sunlit portion of the nucleus, while the dark side of the nucleus is seen in silhouette against the dust behind it. In this false-color image, dark blue represents the darkest areas, red the middle tones, and yellow the areas of greatest brightness. Copyright © 1986 the Max-Planck-Institut für Aeronomie.


GIOTTO
INTEGRATION TURNOVER TROLLEY

of failure estimated, in advance, at one-in-ten.

The Giotto mission's impressive display of technical prowess was matched by the equally impressive international effort underlying its success. "For the first time in history," mused Roger Bonnet, ESA's Director of Scientific Programs, "we have the cooperation of ESA, the Russians, NASA, and the Japanese Space Agency."

Japan and the United States participated in very different ways. Two small Japanese space probes, Suisei ("Comet") and Sakigake ("Pioneer"), flew toward distant encounters with the comet. Sakigake carried a simple plasma experiment and magnetometer, and Suisei carried an ultraviolet camera to image the extended hydrogen halo of the comet. American participation, in the wake of the Challenger tragedy, consisted largely of navigation and ground support plus observational support from a number of spacecraft already in space. One of these, ICE, had already flown past Comet Giacobini-Zinner; now the spacecraft's orbit would bring it within 30 million kilometers of Halley. Another spacecraft, the Pioneer-Venus Orbiter, would make ultraviolet images of Halley near perihelion.

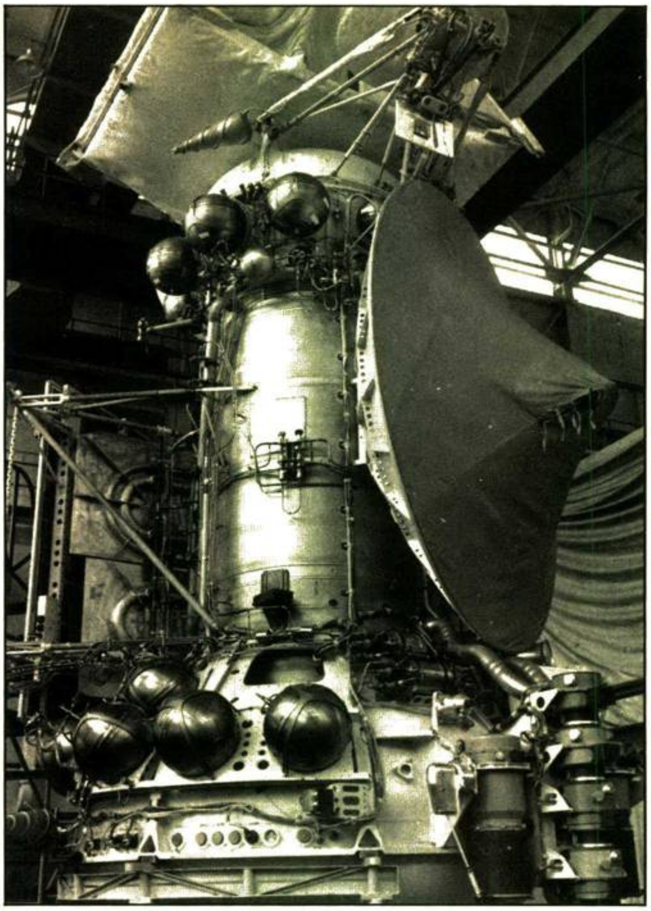
But the Russians had planned twin missions to Comet Halley. Two Soviet spacecraft, named VeGa-1 and VeGa-2 (for Venus-Halley), would fly past Halley on March 6 and March 9, respectively, at target distances of 10,000 kilometers. Whereas Giotto was geared toward direct measurement made from within the comet, the VeGas were designed for remote sensing of the comet. Telephoto cameras and powerful infrared spectrometers aboard the twin VeGas would scan the comet from afar, mapping the broad distribution of gas and dust.

The VeGa spacecraft would provide a vital service for Giotto: navigation. From ground-based measurements alone, Halley's position would not be known well enough to target Giotto. For the spaceprobe to fly within 500 kilometers of the nucleus, the comet's position had to be determined to an accuracy much better than 500 kilometers.

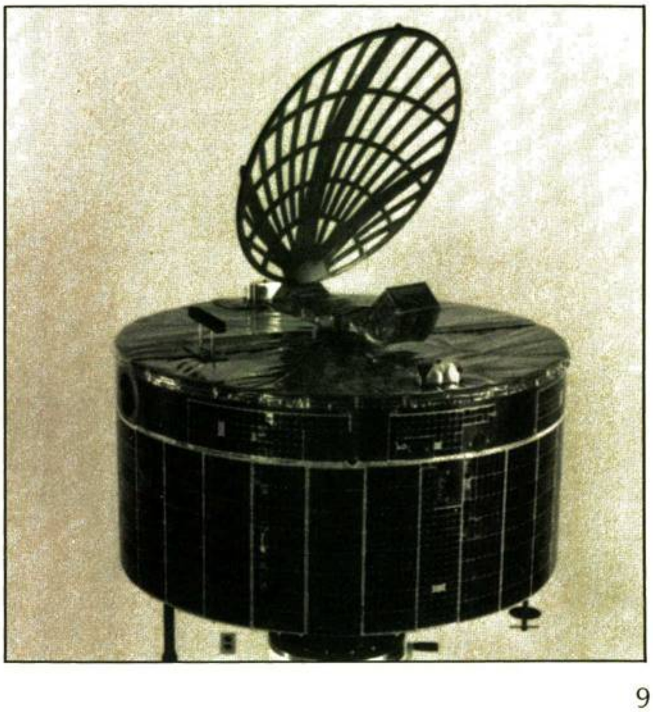
Using the precision navigation capabilities supplied by NASA's Deep Space Network to locate the Russian spacecraft, VeGa-1 would pinpoint the comet. As it flew past Halley, the Russian probe's cameras would image the comet's nucleus relative to itself. With the position of the nucleus accurately known, spacecraft controllers could then reliably tweak Giotto's orbit to fly right where they wanted it with an uncertainty of perhaps 30 kilometers.

Giotto speeds closer and closer to Comet Halley. New pictures flash on television monitors. The tiny pinpoint nucleus grows and becomes visible in the swirl of gases. It is visible even in the gaudy false-color contours of the

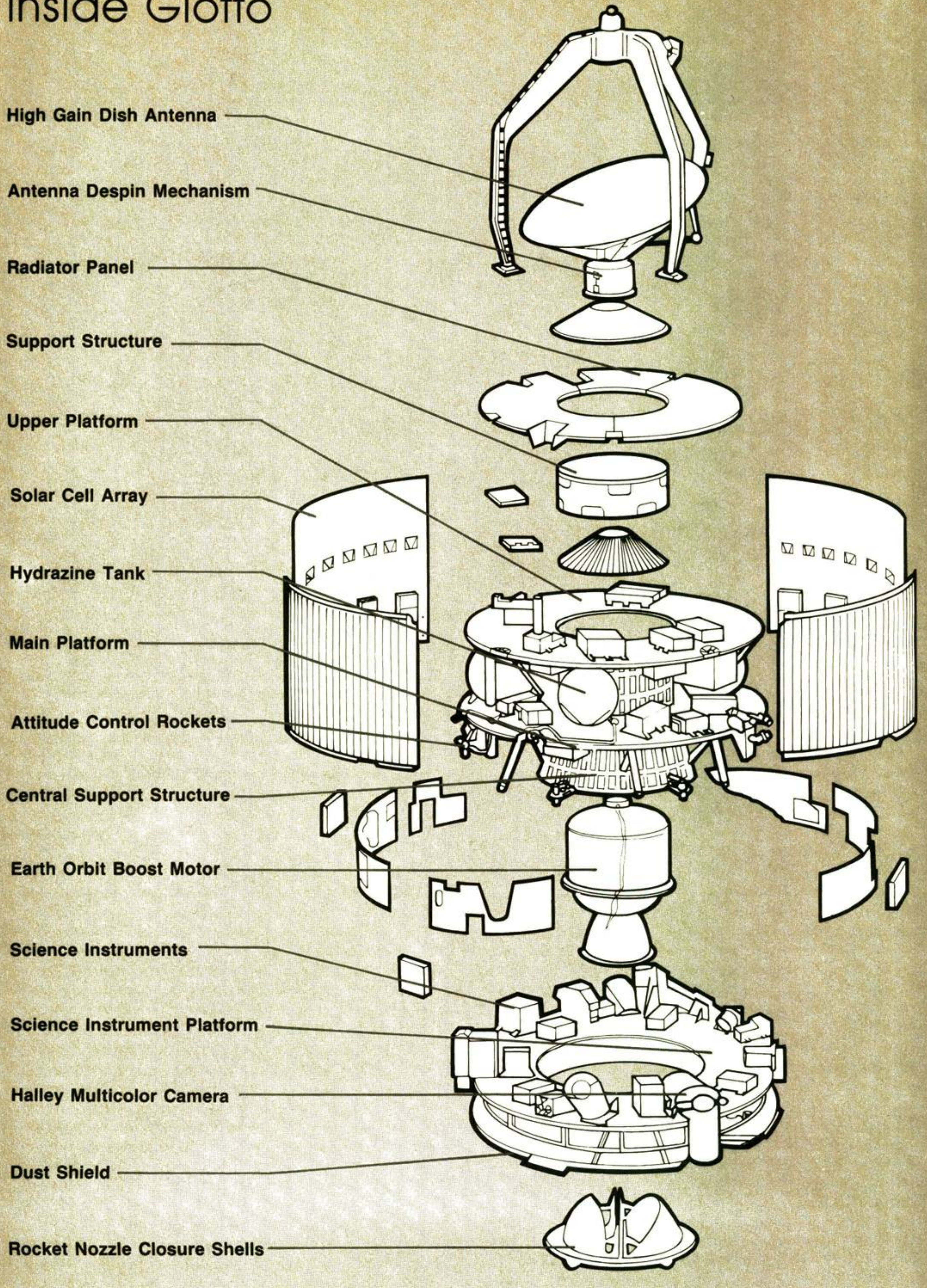
Three meters high and 1.8 meters in diameter, the cylindrical Giotto spacecraft has an Earth-pointing antenna at one end and a dust shield at the other. Many of the scientific instruments are on the lowest level, protected from direct impacts by the dust shield system. The sides of the spacecraft are covered with solar cell arrays. In this picture, which was taken during spacecraft integration at Intespace, an aerospace firm in Toulouse, France, the right solar array has not been installed. The silvery sphere is a hydrazine tank used for maneuvering and attitude control. The Halley Multicolor Camera is the white cylinder sticking out of the lower left side of the spacecraft. European Space Agency photograph.



Two Soviet spacecraft (above) encountered Comet Halley, VeGa-1 on March 6 and VeGa-2 on March 9. The VeGas flew past Venus last June, dropping probes into the Venusian atmosphere before continuing on to fly within 10,000 kilometers of Halley. VeGa is a Russian acronym for "Venus-Halley." Because the "H" sound is represented by a "G" in the Cyrillic alphabet, "Halley" is spelled "Gallei" in Russian. The Japanese Suisei and Sakigake spaceprobes (below) encountered Halley at long range — some 150,000 kilometers for Suisei and 8 million kilometers for Sakigake — and sensed the comet's ultraviolet emissions and plasma environment.



Inside Giotto


High Gain Dish Antenna
Antenna Despin Mechanism
Radiator Panel
Support Structure
Upper Platform
Solar Cell Array
Hydrazine Tank
Main Platform
Attitude Control Rockets
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Earth Orbit Boost Motor
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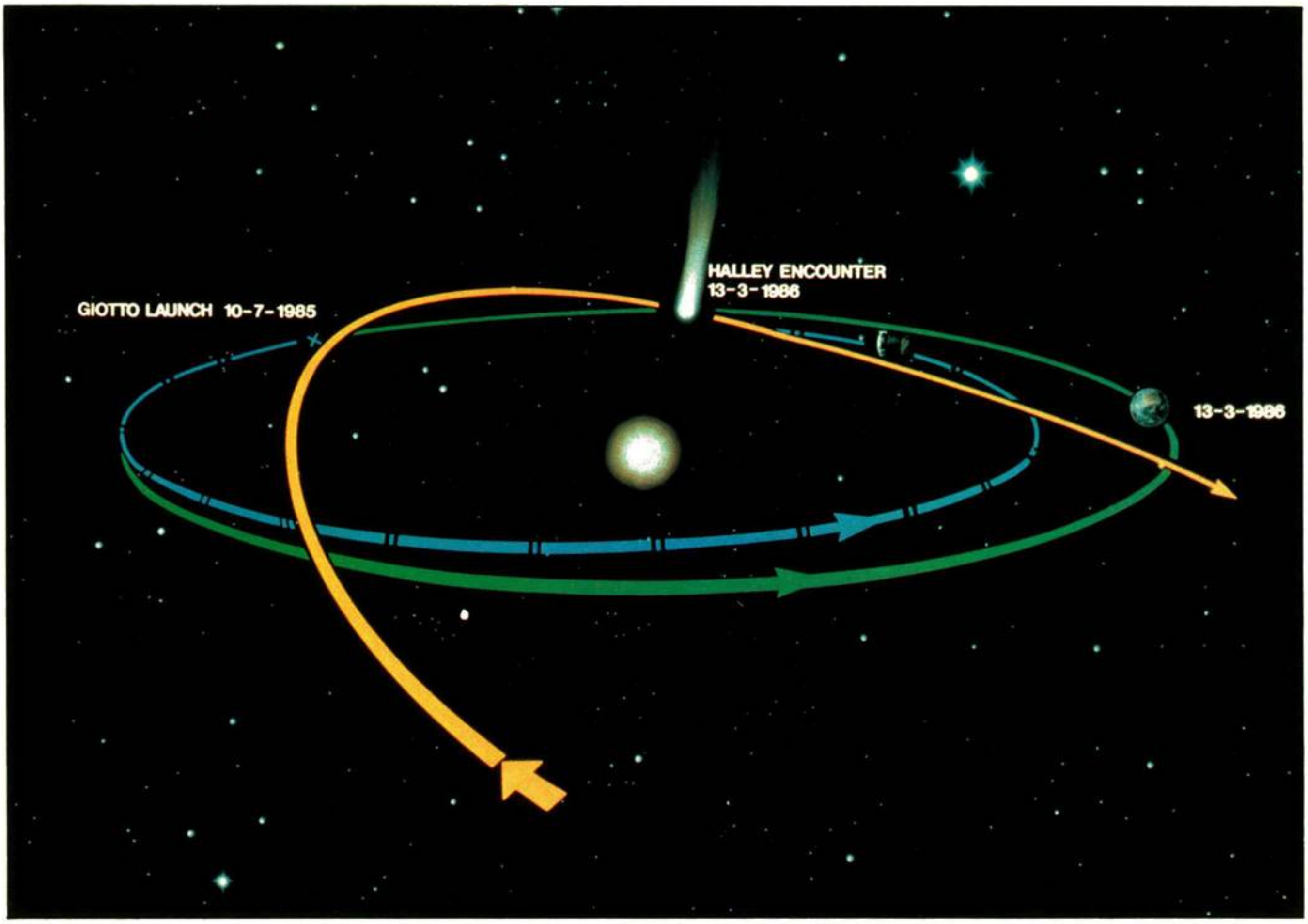
Science Instrument Platform
Halley Multicolor Camera
Dust Shield
Rocket Nozzle Closure Shells



Launched from Earth on July 2, 1985, Giotto traveled inside Earth's orbit to reach Comet Halley. The spacecraft and comet met, going in opposite directions, during the first few minutes of March 14, 1986. (Dates on chart are planned, not actual, times.) Earth's orbit is shown in green, Giotto's in blue, and Halley's in yellow. ESA diagram.

television display. With each minute Giotto draws 4,100 kilometers closer to the nucleus of Halley's Comet. Dr. Wolfgang Schmidt, of the imaging team, serves as our commentator.

C/A-17 minutes (70,000 kilometers range): "The nucleus is in the center of the picture right now, seen here in black and white, now at a scale where the brightest point really covers the nucleus itself. Now come in the pictures even faster . . . . The blue dot in the middle, the blue area in the middle . . . you see how always the bright area in the middle, and we believe, that this is the iceberg as distinct from the gases and dust around it."

C/A-14 minutes (57,000 kilometers range): "Once more a real-time picture — and the shape of the inner area stays the same, so we can assume that it is the nucleus we're seeing. Of course, careful analysis has to show that this statement is really true.

"At the present time we are certainly at this short time scale unable to make that analysis, but, uh, I must certainly say that the fact that the shape stays the same and only increases in size. So for the first time I think we really see now the nucleus."

C/A-13 minutes (53,000 kilometers range): "The size of the picture is now much larger so that part of what we see is already structure on the nucleus — so it's not all gas or jets, but it's an odd-shaped potato with structure on it."

C/A-10 minutes (41,000 kilometers range, mission control speaking): "We see now that there is a small deviation in spacecraft attitude; we'll try to get someone from the flight dynamics to make a comment on that."

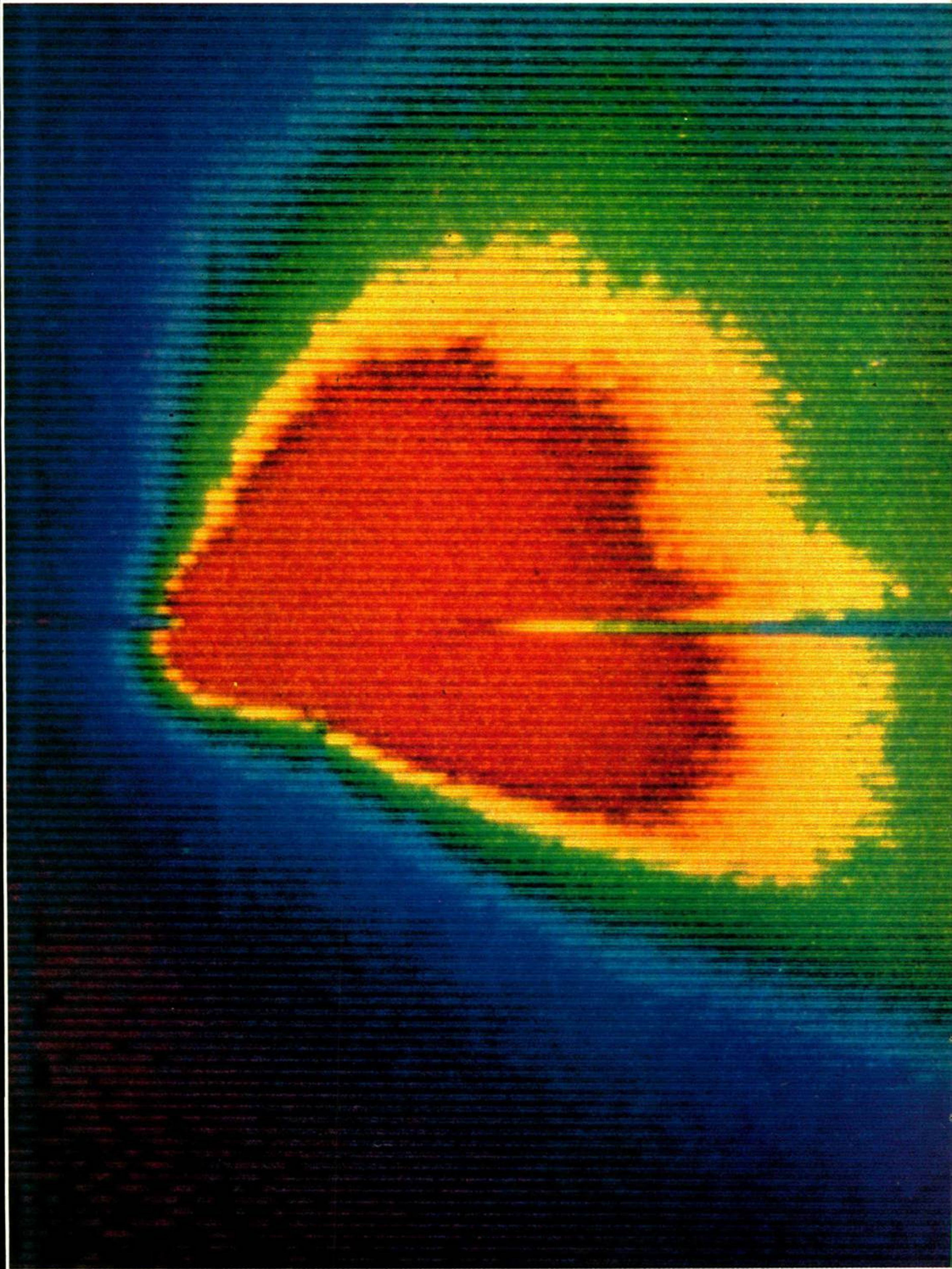
C/A-7 minutes (28,800 kilometers range): "So, we still have seven minutes to go. In those 400 seconds until closest approach, we will be moving from something like 28,000 kilometers in to 500 kilometers, so the timescale, the zoom, now gets faster and faster."

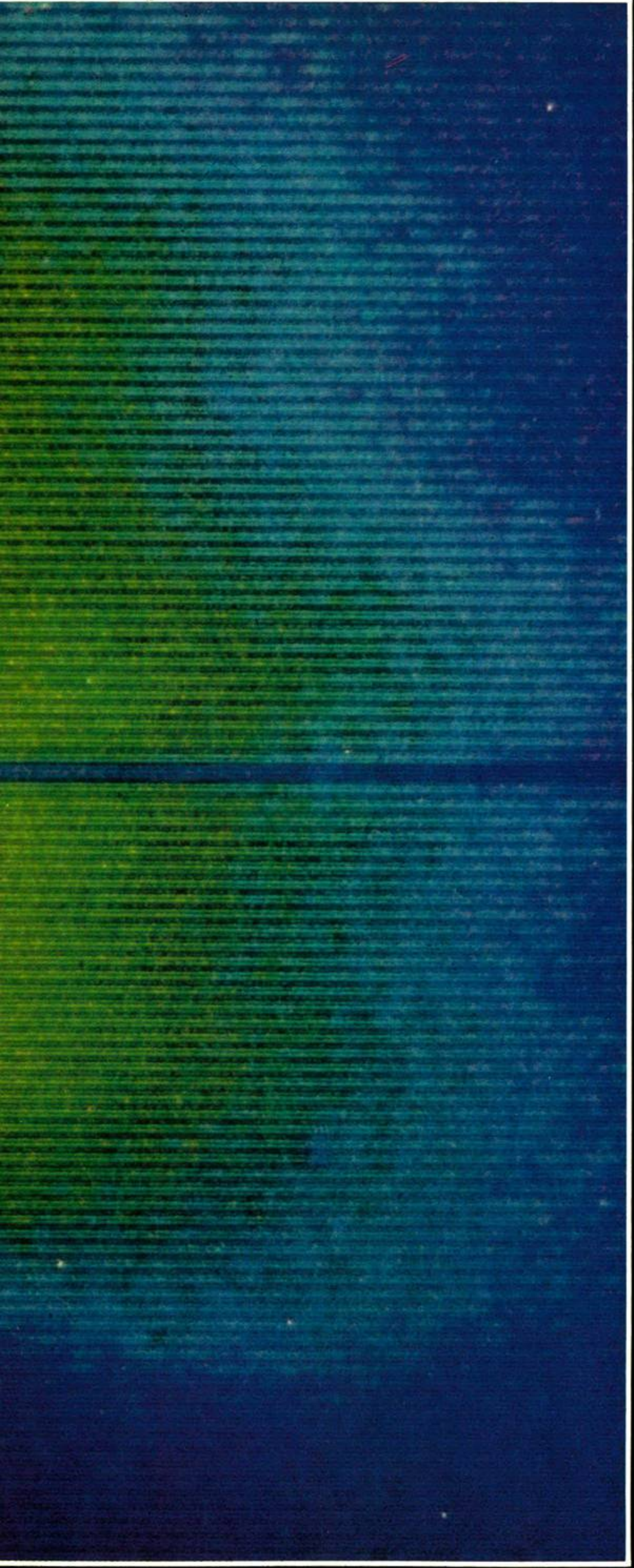
C/A-6 minutes (24,600 kilometers range): "The size of our picture will increase by a factor of two within three minutes, but the next time it will halve in one and a half minutes, and then once more by a factor of two."

The minutes slip by. The camera switches to nucleus mode, returning image data every four seconds. Brightly colored frames flash across the television monitors — large square frames followed by tall, thin frames, then by small rectangular frames — a set of images for each rotation of the spacecraft, spinning once every four seconds.

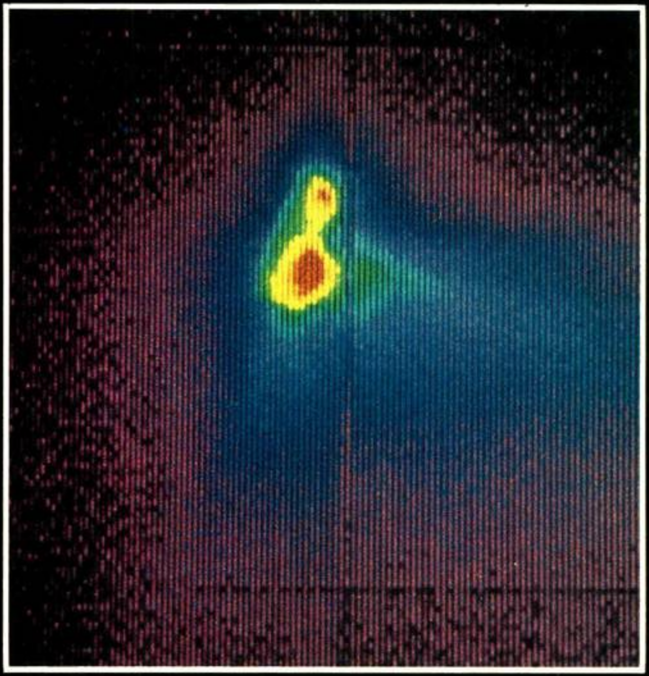
C/A-4 minutes (16,400 kilometers range): "We are approaching on a line which comes from slightly behind the comet, as seen toward the Sun, so the sunward side is not fully visible yet. The probe goes around the comet, so to speak. It first sees it slightly from behind, and then from the side, and then more and more from the side where the Sun is shining on the comet."

C/A-3 minutes (12,300 kilometers range): "Now we are at a distance where the nucleus fills already, begins to fill the picture, and ah, humm, we are now three minutes away, which is roughly 180 seconds, and that is a distance of 12,000 kilometers and so we see

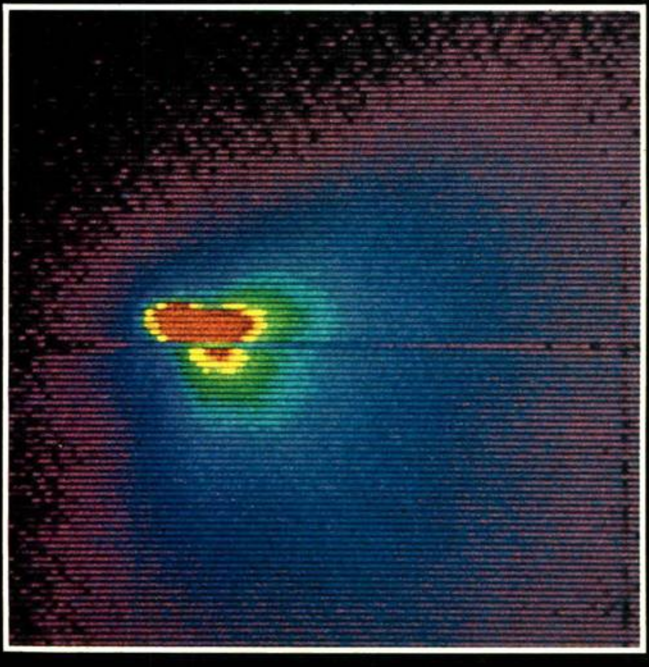




VeGa

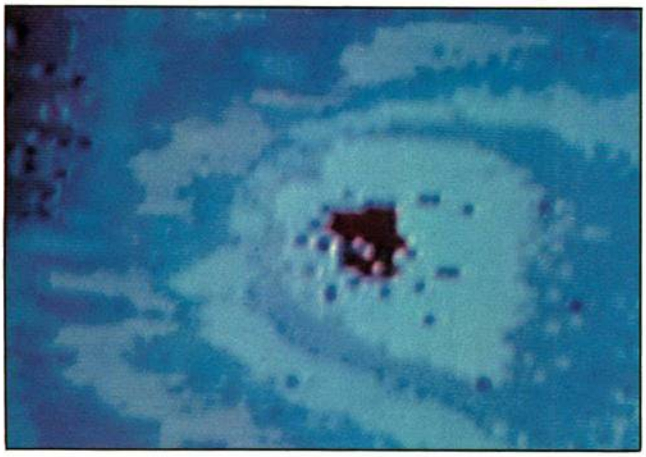


VeGa-2's television cameras, equipped with 200mm focal length lenses, returned these views of Halley's inner dust cloud and nuclear region. Left: Before the flyby, the images reveal a broad fan of dust pointing toward the Sun. Above: At closest approach, Halley appears as twin blobs. These are possibly the cores of the two bright dust jets seen five days later by Giotto's cameras. It is not certain whether the nucleus is visible in the Russian images. Below: After the flyby, VeGa's cameras show a bright dusty region. The central part may be the nucleus, or it may be a dust blanket surrounding the nucleus. VeGa-2 images provided by the Laboratoire d'Astronomie Spatiale, CNRS, France, courtesy of ESA.

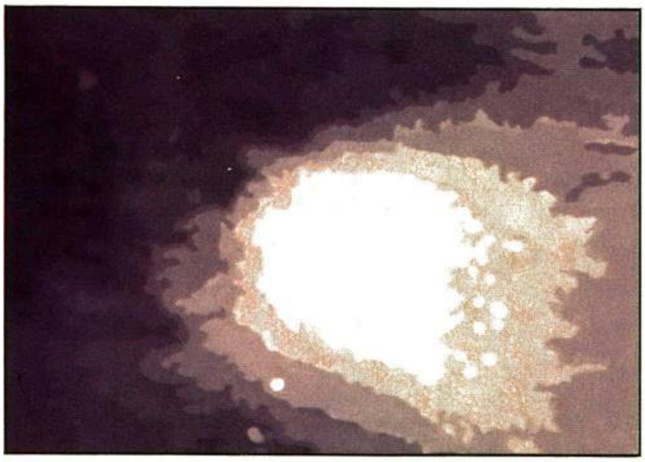


Viewing False-Color Pictures

Halley's Multicolor Camera images left many viewers, especially those who saw them on television, wondering just what they had seen. Displayed as contoured false-color images, the pictures were difficult and sometimes all but impossible to interpret. Since the camera returned its images to Earth as strings of numbers, the camera team needed to reconstruct the output quickly for "quick look" viewing. Rather than using a scale of gray tones to encode the numerical data, they substituted arbitrary color values. Each color represents a different brightness level in the image.



This false-color presentation shows part of the nucleus and the largest dust jet. Quick-look Giotto images appeared in this form. Television image courtesy of ESA.



A gray-scale representation of the same image. Note that the jet now looks bright and the shadowed surface of the nucleus looks dark. Final image will show more detail.

something, well, I don't know the exact scale.

"We clearly see that everything grows. We are racing with these 70 kilometers, or 68 kilometers per second, toward this tiny body of three kilometers of radius. Soon we will see it from a distance of 8,000 kilometers. The probe will probably go even nearer than the scheduled 500 kilometers, that is we still will get a zoom of more than a factor of ten beyond what we are seeing here.

"On the last frames hopefully, if the camera works throughout, of course it's in danger, but if it does, um, then, um, then we see part of the nucleus, see more and more details."

C/A-2 minutes (8,200 kilometers range): "Now it's obvious there is structure on this nucleus. Now we look at almost something like mountains or little hills and um, a crater. Analysis has to show whether this is a deepening or a height or only apparent as white snow as against the surrounding parts which might be dark dust, uh . . . ."

C/A-85 seconds (5,800 kilometers range): "Well, we see uncredible [*sic*] detail. I personally must say I didn't expect that the pictures would show so much detail and to such a low distance."

C/A-64 seconds (4,420 kilometers range): "Now I think we are very close to closest approach and now we should go around the nucleus. Let's see whether the camera can nevertheless follow the comet. It has, of course, to turn around and that has to be done automatically."

C/A-30 seconds (2,140 kilometers range): "And still scales are increasing and so, and we see recognizable detail from picture to picture so the camera is working marvelously well, and also the spacecraft . . . ."

C/A-15 seconds (1,160 kilometers range): "And still come pictures, still more detail! We're now looking at scales, well . . . ."

C/A-10 seconds (blank TV frame appears): "I, um, which . . . ."

C/A-3 seconds (second blank frame appears): "Uh, yeah."

Closest Approach (cheers, clapping in background).

C/A+6 seconds (mission control speaking): "We now have a signal drop on the Parkes data. This is being investigated immediately by the team in the back row here. We'll keep you up to date as to what they see. Up until that time everything had been progressing as normal as regards the spacecraft systems."

C/A+45 seconds (mission control speaking): "I can report that the data is now indicating bad for both the Parkes source and the DSN backup source. It hasn't gone to the drop status on the M3S displays, but we're watching that closely."

C/A+60 seconds (voice in background speaking): "DSN receiver locked in."

C/A+78 seconds (mission control speaking): "We can report that the DSN station is reporting it's getting lock again. The data indications are still bad, but they have not gone to a drop state which means no data."

C/A+3 minutes: "This is Peter Wentzel speaking. I am live-connected via telephone to the HMC science center. The last image we had was from about 1,500 kilometers from the nucleus. It was 18 seconds before closest approach. About two or three minutes before the cameras switched into nucleus mode. That means all the CCDs were operating simultaneously and images in four colors simultaneously were received. I hear a big clapping and very happy sounds from the HMC science center. If you'll just stand by I'll check again what the latest is. Wolf, da gibt's etwas zu sagen? Hallo? All' zufrieden. Ja, Ja."

C/A+5 minutes (mission control speaking): "The operations team has just reported that the DSN station has just obtained lock again on the Giotto signal. We still read bad data here at ESOC; we're waiting for a change in that status."

* * *

For the next eight hours, science and spacecraft operations teams worked to understand what had happened to the spacecraft and to examine the wealth of data Giotto had returned. Closest approach had occurred at 00:03:00 Universal Time on March 14, five seconds later than predicted. Two seconds before the time of closest approach, at 00:02:58 UTC, one or more asymmetric impacts had caused the spacecraft to wobble so that its radio antenna no longer pointed continuously toward Earth.

At the big dishes in Australia, the signal had varied erratically, dropping as much as 18 decibels in strength, then coming in again. Even though real-time telemetry "lock" was lost, ground stations never lost the signal carrier wave so most of the information transmitted from the instruments could be recovered from tapes of the flyby. Giotto's onboard nutation dampers had worked to combat the wobble, so that 34 minutes after its loss, the signal was re-acquired. Navigation data from the camera showed that Giotto had passed 605 kilometers from the heart of the comet.

Although still functioning, Giotto had not escaped unscathed. Four of the experiments, including the camera and two of the mass spectrometers, appeared to be dead. The star mapper, used for spacecraft orientation, was misaligned but still working, and the lower end of the spacecraft was heating, an indication that the thermal control system wasn't working. As flight director David Wilkins described it, "We think there's significant damage at the lower end; there may be more than a hundred penetrations of the dust shields."

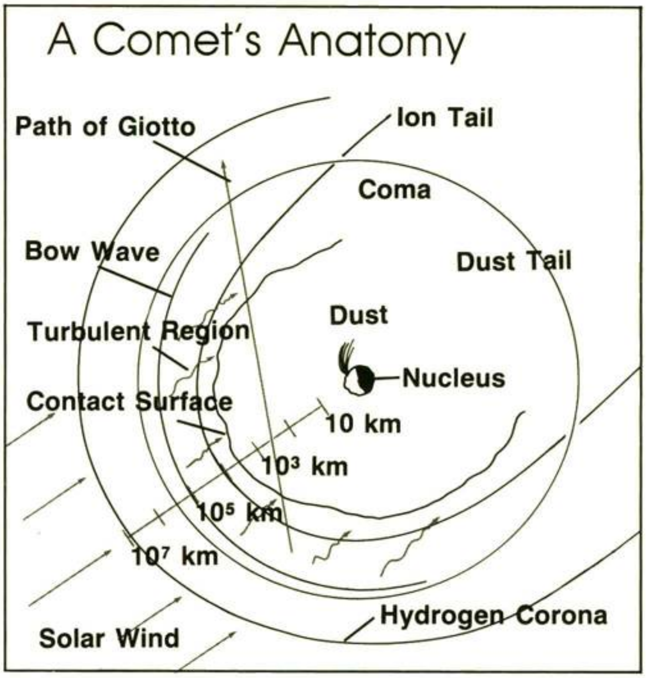
The camera had obtained a series of more than 2,000 images at ranges from 767,000 to 1,350 kilometers, including 69 images in three-color nucleus mode. The best had a potential resolution of some 50 meters — half the length of a football field. Because Giotto had approached Halley from behind, the images showed the nucleus partially in shadow. Preliminary analysis gave the long dimension of the nucleus as 15 kilometers by as much as 10 kilometers wide.

Because the nucleus lay within a bright cloud of dust, its dark, inactive end was silhouetted against the dust behind it. The sunlit side of the nucleus was obscured by two major bright dust jets roughly 8 kilometers apart. At least one smaller jet was visible. The largest jet extended at least 15 kilometers into space; the smallest extended some 5 kilometers.

Dr. Horst Uwe Keller, principal investigator of the camera experiment, pronounced the nucleus very irregular and black as velvet, with a concavity in the middle, like a potato or a peanut in shape. About the sunlit end, he said, "We see strong activity, with concentrated beams of dust coming out. The activity is irregularly distributed around the surface. Almost all of it is on the sunward side." According to co-investigator Dr. Klaus Wilhelm, "We looked at some of the images, the last ones, and it appears there is some type of nozzle sitting on the small tip of this potato, and from this nozzle the jet is coming out."

The camera had functioned until nearly two seconds before closest approach. "We lost the system very suddenly," said Keller, "probably connected with an anomaly in the voltage supply. We lost voltage for some time, and probably also had some mechanical damage. Afterwards we saw some indications of mechanical damage. I think it was a dust impact."

Dr. Wilhelm added: "We saw a very sudden decrease in structure and contrast at around 22 seconds [approximately 1,500 kilometers] before closest approach, as if we were hit by a number of dust particles very suddenly. We still got pictures, but they had very much less contrast after that." Apparently the camera's viewing mirror was frosted by impacts of countless small particles during the flyby.

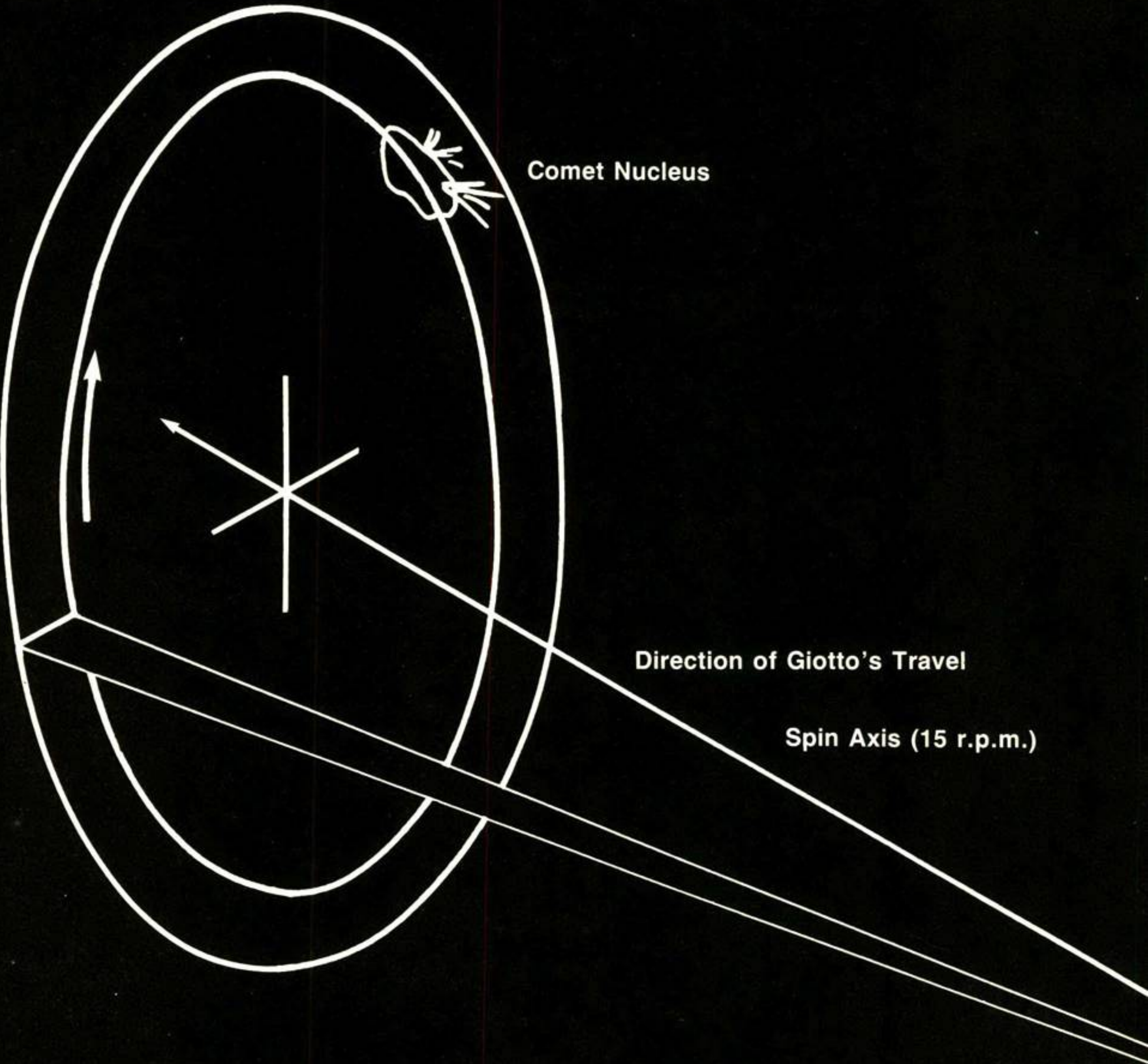

A Comet's Anatomy

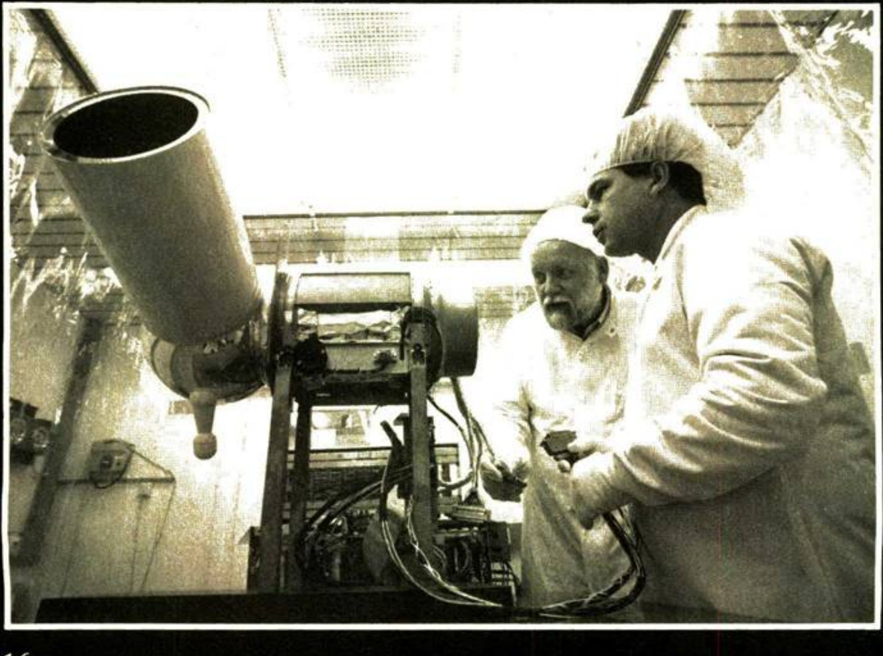
At the core of a comet is the icy nucleus. When heated by the Sun, the nucleus spews gas (mostly water vapor) and dust into space. This ejected material comprises the coma, a dense cloud surrounding the nucleus. The impinging solar wind, a stream of ionized particles from the Sun, interacts with the cometary gas and dust. Where they collide is the bow wave. Comet material flows away from the Sun, forming two tails, one of ionized gases and one of fine dust.

Giotto's experiments to measure the chemical composition of the gases boiling off Comet Halley, the mass spectrometers, were extraordinarily successful. "We were just overwhelmed by the richness of the spectra," announced Dr. Dieter Krankowsky, principal investigator of the neutral mass spectrometer. The largest concentrations of neutral atoms and molecules lay at 16, 17, and 18 atomic mass units — water vapor and its breakdown products. "We can definitely say that mass 19, H_3O^+, is the dominant ion we saw," he added.

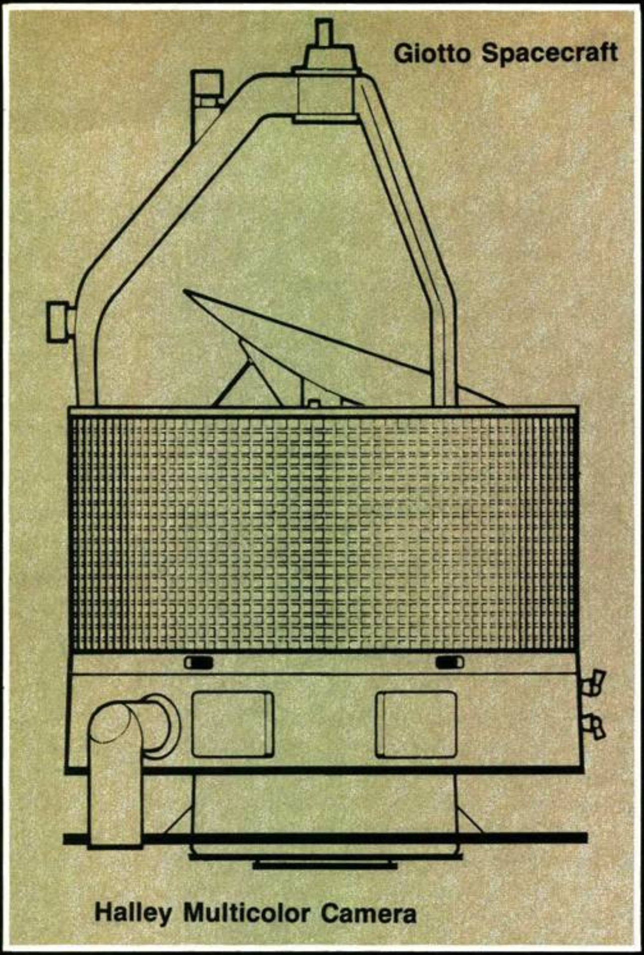
The preliminary estimate of the production rate — the amount of gas given off by the comet — was $2x10^{30}$ molecules per second, roughly 60 tons per second. "That figure may be in error by a factor of two," added Krankowsky. "We first picked up water vapor 100,000 kilometers out, and it increased toward the nucleus roughly proportional to one over r-squared." But, he added, "there is actually much more structure [in the comet data] than the smooth curves we have drawn so far." Although water ice is the major volatile in Comet Halley, Giotto's sensors will tell astronomers about the rich variety in the chemical makeup of Halley's primordial ice.

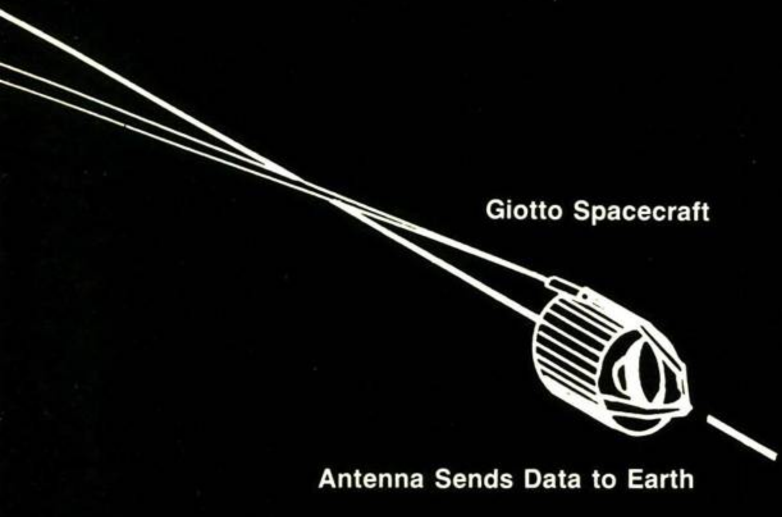
Impacting at 68.4 kilometers per second, dust was a real hazard for Giotto. Dust was also one of the major scientific concerns. As it turned out, the dust particle experiments showed far fewer dust particles than had been predicted. Large dust particles especially seemed in short


Comet Nucleus
Direction of Giotto's Travel
Spin Axis (15 r.p.m.)



The "eye" of the Giotto spacecraft is the Halley Multicolor Camera. Dr. Horst Keller (left) and Christian Becker pose beside the 12-kilogram instrument, shown here in a cleanroom environment. Before integration into the spacecraft, the camera underwent rigorous laboratory testing to insure that it could and would — automatically and autonomously — track and record the comet nucleus. MPG-Pressbild/Blachian photo.




Giotto Spacecraft
Antenna Sends Data to Earth

Halley Multicolor Camera

When Giotto flew past Halley, its camera had to locate and track the comet's nucleus without instructions from Earth. Giotto, at the time of flyby, was nearly one astronomical unit from Earth so a radio signal there and back would take 16 minutes — far too long to be of any use to a camera traveling at 247,000 kilometers per hour.

Adding to the complexity of tracking Halley, Dr. Horst Keller, principal investigator for the camera team, commented, "We're observing from a spinning spacecraft so the camera sees the object only a few milliseconds per spin. It's a very complicated operation to follow the nucleus." Giotto, which is spin-stabilized, rotates 15 times per minute. The camera's field of view thus traces a circle in the sky, with the image of the comet crossing the field of view of the camera for a short time during each rotation. The camera must recognize and follow the subject and know when it is in the field of view.

The camera's optical system is a precision reflecting telescope of 16 centimeters aperture and 1 meter focal length. Its optical parts weigh only 1.2 kilograms. Most of the optical system and electronics package are inside Giotto, protected by the dust shields. The camera views the comet in a mirror, which is made of metal so it won't shatter if struck by dust grains and protected by a long light baffle outside the spacecraft.

Three microprocessors in the camera electronically control the camera, detecting the brightest part of the scene and zeroing in on it. "It's helpful," explained Dr. Klaus Wilhelm, "that there are no bright stars nearby to confuse the camera." As Giotto draws close to the comet, tracking becomes even more complex because the spacecraft moves toward the comet at a rate of nearly 300 kilometers during each 4-second rotation. The computers must predict where the comet will appear on Giotto's next rotation and move the camera to the proper place in advance.

Obviously the Halley Camera doesn't use ordinary film. Instead, it uses charge coupled devices (CCDs) to sense and store the image for transmission back to Earth. "They're the most modern and sensitive we could find," says Dr. Keller. Each CCD, measuring 292 by 390 pixels, operates with only a few rows of pixels exposed to light, leaving the camera's motion to scan the sky across the CCD. The remaining lines, which are masked off, serve to store the image until readout. A linear diode array, also at the camera's focus, provides data to the computers for locating and tracking the comet.

Operating an intelligent camera in space isn't without its problems, even when the camera functions perfectly. Says Dr. Keller, "The last image where we could detect the surface of the nucleus was taken about fifty seconds before encounter, from a distance of about 3,500 kilometers. Of course, we took images closer in, but since the camera tracked the jet, which was the brightest part of the scene, the sharpest pictures show only the jet."

After Giotto's data are received at the giant Parkes radio telescope in Australia, the Australian Deep Space Network station, or ESA's ground stations at Carnavon or Weilheim, they are split into ten separate data streams for the individual experiments. A control console scientist, or "payload operations engineer," monitors the requests of individual science experiments, checking that changes in one instrument will not adversely affect the other instruments.

supply. As Professor Tony McDonnell wryly noted, "We were afraid the instrument was dead." The first large impact came 70 minutes before closest encounter, some 287,000 kilometers out, "but the next big one didn't occur until T minus 2 minutes. The flux rate remained low until [Giotto was] very close to the nucleus." Typical "large" dust particles weighed 30 micrograms, the size of a small grain of sand.

Medium size dust, dust the size of cigarette smoke particles, was also in short supply. The first impacts occurred 150,000 kilometers from the nucleus. More particles were encountered between 120,000 and 90,000 kilometers out, then the impact rate fell. Closer than 70,000 kilometers, it rose again. For the very finest dust, dust particles down to 10^{-17} grams in mass and not much larger than the wavelength of visible light, the flux rate was also very much lower than predicted. It was not until 20 seconds before closest approach that the counts rose so high the equipment could no longer keep pace with the impacts.

At closest approach, the picture of Halley as a comet with a scarcity of dust suddenly changed. In the final minute before closest approach, Giotto ran into what the astronomers called "a wall of dust." Said McDonnell, "We had a very low flux rate on the penetrating particles, but they came right in at the end." One hundred or more of the larger particles knocked the spacecraft into a wobble. Giotto's dust detectors probably recorded the impacts of the dust grains that knocked it askew. According to McDonnell, "We know from the time it takes [for the spacecraft to precess] that the impact occurred in the region where we were gathering data. That data is being reconstituted, and will enable us to determine the impact position of those particles."

Giotto's radio signal, too, yielded important dust data. The spacecraft, of course, slowed as it slammed into hordes of fine dust particles. By monitoring the Doppler shift of the radio signal, the total dust could be measured. The result was striking: expecting a total change of a little more than 2 Hertz in the signal, the experimenters observed a change of 16 Hertz. Giotto was slowed a total of 70 centimeters per second by dust. Halley had plenty of dust, but it was strongly concentrated toward the nucleus. And, as project scientist Roger Bonnet said in summary: "We now know that a large fraction of the dust comes from active regions in the form of dust jets. It's a very inhomogeneous dust environment. To me, this is perhaps the biggest surprise [to come from the Giotto mission]."

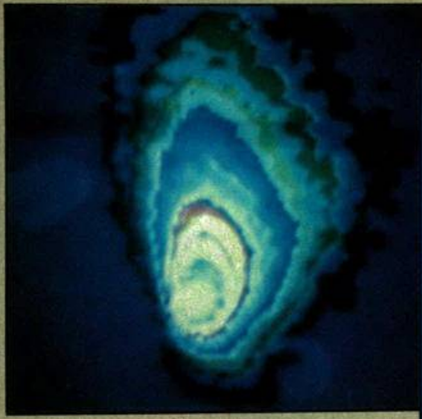
"It is clear from what we've seen so far," said Dr. Alan Johnston, "that the interaction between the comet and the solar wind takes place over a very large distance — at least 7 million kilometers — and that it's also a very complicated interaction with a great deal taking place outside the bow wave, which is normally reckoned to be where the interaction starts."

Giotto's plasma experiments explored the magnetic and charged particle environment of the comet. Some 7.8 million kilometers from the nucleus, Giotto detected plasma waves, which grew gradually in intensity. It passed the bow wave, where the solar wind slows and tries to squeeze around the comet, 1,150,000 kilometers out.

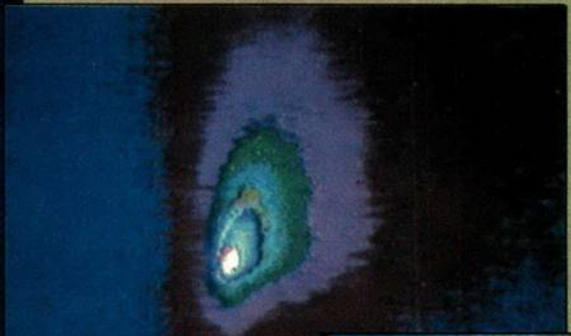
Inside the bow wave, as it approached the nucleus, Giotto flew through twisted magnetic fields and turbulent streams of plasma coming from all directions, which, as the spacecraft penetrated deeper and deeper into the comet, eventually gave way to smooth flows. Giotto's sensors detected ions of many types. The breakdown products of water molecules — H_3O^+, H_2O^+, HO^+, and O^+ — were most abundant. So were the carbon and nitrogen ions CO^+, CN^+, N_2O^+, HCN^+, CO_2^+, and N_2^+, as well as S^+ and S_2^+, and the metal ions Fe^+, Co^+, Cu^+, and Ni^+. There were even mystery ions with an atomic mass near 100.

As determined by the mass spectrometers that constantly monitored the gas environment of the spacecraft, Giotto encountered the contact surface, the boundary inside which solar wind particles cannot penetrate, some 4,300 kilometers from the nucleus, just 65 seconds before closest approach.

Inside the contact surface, Giotto found a very cold plasma. This material came entirely from the comet itself.



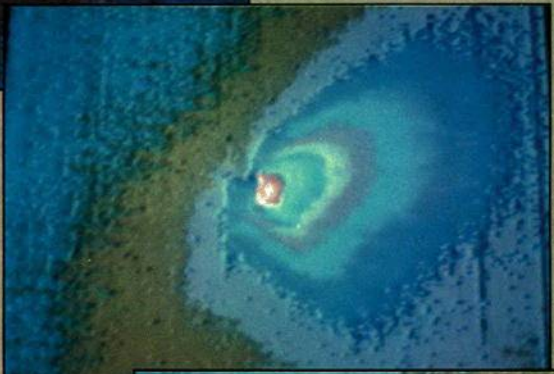
Halley's inner coma shows smooth brightness contours.



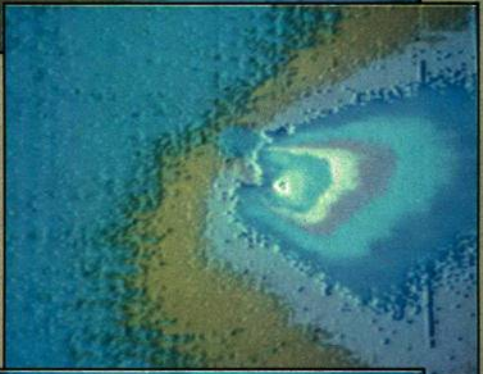
We see a fan-shaped dust sheet. This view is 300 kilometers wide.

Zooming Toward Halley

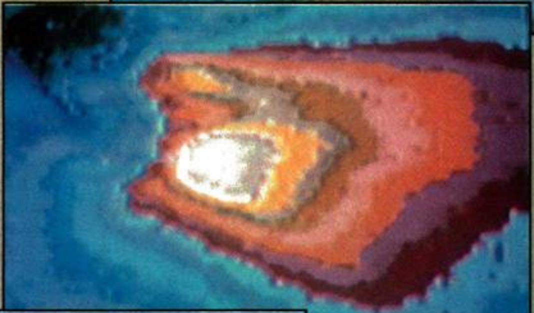
As Giotto sped toward Halley, its camera returned over 2,000 images; during the last five minutes before encounter, these included one set of color images every four seconds. As Giotto drew closer to Halley, the camera had to automatically point at and follow the nucleus through space. Because it was designed to track the brightest area of the comet, the camera ultimately shot its closest pictures, made at a range of 1,350 kilometers, centered on the brightest dust jet.



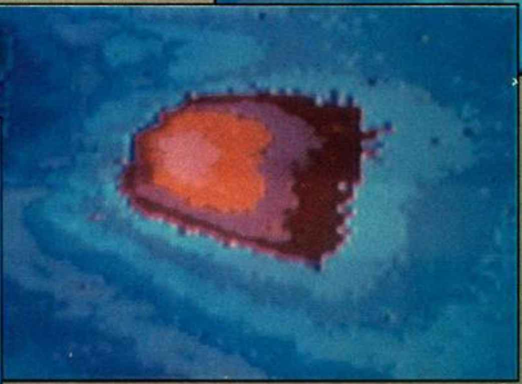
The dark side of the nucleus appears yellow here. This view is 150 kilometers wide.



We see the nucleus dark against dust behind it. This view is 75 kilometers wide.

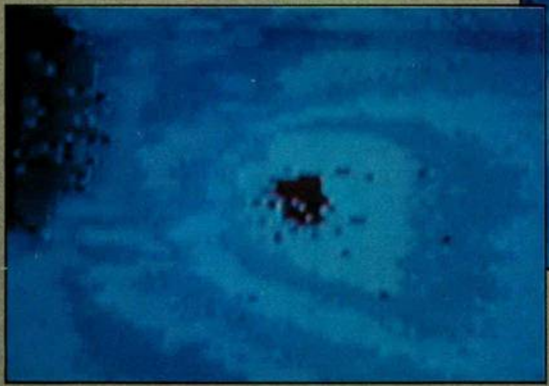


The dark tip of the nucleus and two jets are visible. This view is 25 kilometers wide.

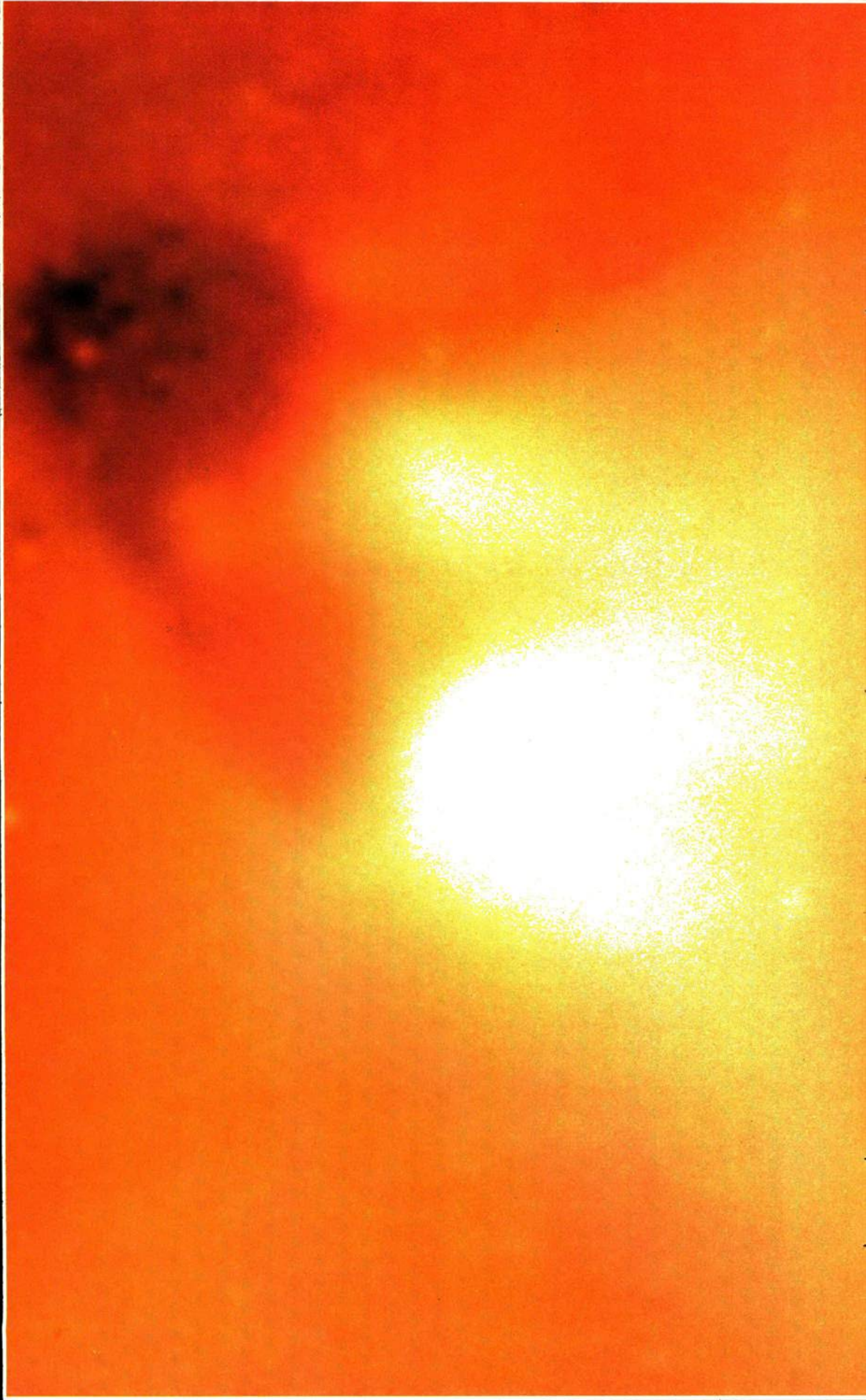


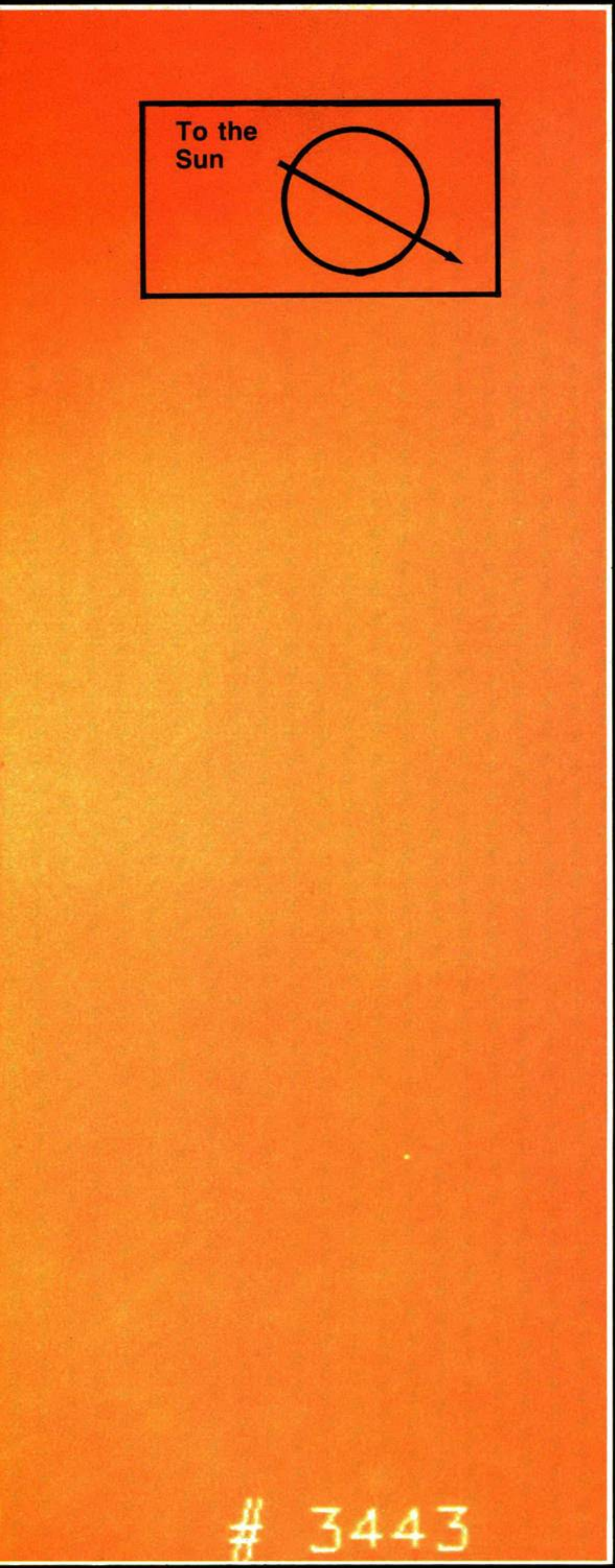
Red isophotes outline the brightest jet. This view is 15 kilometers wide.

The core of the brightest jet appears red. This view is 10 kilometers wide.

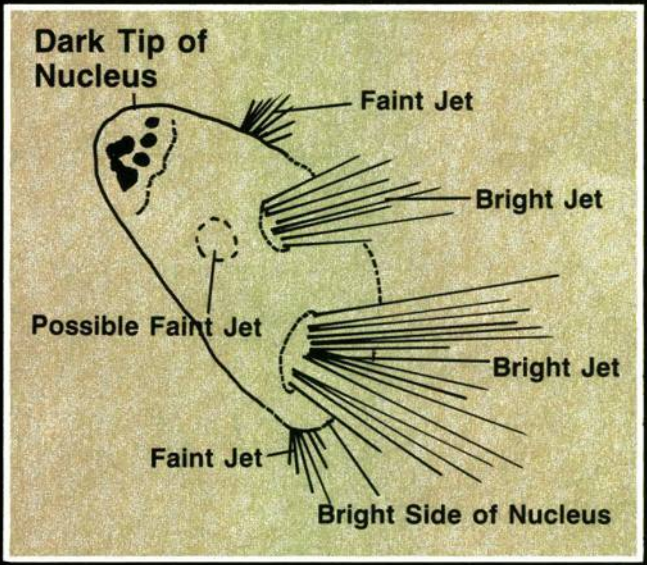


Television imagery courtesy of ESA.





Giotto



"In this image, taken at a range of about 20,000 kilometers, you see the outline of the nucleus. This picture shows the whole nucleus. In later pictures from closer range you see more and more the lower tip and the bright jet there, but less of the nucleus itself.

"The nucleus is about 15 kilometers from top to bottom. Its size in the other direction is very difficult to judge because you cannot see the total width because of the activity of the dust ejection. The size is an important result. The nucleus is appreciably larger and darker, at least twice as large, as we thought it was before the flyby.

"The dark patch is part of the cometary nucleus where it's not illuminated by the Sun. It's like the Moon with the Sun lighting only a crescent. On the sunlit side, you see the jet activity. The comet is dark compared to the bright background, bright due to scattering of sunlight by the dust.

"You can see a lot of detail. If you look closely, you will see that the surface is very irregular. The nucleus does not have a ball shape; it's not a sphere. Instead, it is elongated and has an indentation in the middle. You could compare it to a peanut, or a potato, or a banana, or whatever you like. The point is that it's hollowed out in the middle.

"The nucleus is black. In fact, both the dust and the nuclear surface are exceedingly black — and I'm talking blacker than coal — something like as black as velvet. It is very similar to the lowest albedos detected so far in the solar system.

"In terms of the scientific yield, I think we lost an appreciable part of the imaging system's potential when we lost the signal just before closest approach. We had hoped to look at the nucleus from both sides and get a better assessment of the volume. We also could have learned a lot if we had been able to look at different phase angles of the dust and so on, and you must also keep in mind that the other side would have been better illuminated. Instead of seeing the nucleus in shadow, we would have seen Sun-illuminated surface."

— Commentary by Dr. Horst Keller

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Darmstädter Echo

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Proud of their accomplishment in space, the European press covered Giotto at length. The mission dates back to NASA's comet mission planning in the mid-70s, when Europe was invited to participate in a flight to Comet Halley. After NASA cancelled its mission, ESA seized the opportunity to "go it alone" with its own mission. Space agencies, industry, and universities in many European countries participated in the project.

Deeper still, and just before closest approach, Giotto crossed the ionopause and flew through a cold, quiet region where the magnetic field strength dropped to zero. Mixed with the cold plasma in the magnetic cavity were energetic ions, whose source of energy puzzled Professor Hans Balsiger: "We don't know what it means, but it was a short-lived phenomenon we saw just before the loss of signal."

Dr. Susan McKenna-Lawlor, principal investigator of the energetic particle experiment, likewise found unexpected phenomena deep inside the comet. "Something quite exciting is happening here as we arrive at closest approach," she said, pointing to a graph of energetic particle data. "I don't pretend to understand what it is. We know very complicated things are going on at the spacecraft itself."

Data from the Giotto mission will take months, even years, to fully assess and analyze. Combining the Giotto science results with the rich yield of data from the VeGa flybys, the Suisei and Sakigake missions, and ground-based observations from all over the world will take even longer. But Comet Halley has, at long last, yielded many of its secrets to the probing inhabitants of the third planet.

Emphasizing the role of international cooperation in the VeGa and Giotto missions, Academian Roald Sagdeev, head of the Soviet Space Research Institute and the man in charge of the VeGa missions, said: "In Halley, we have seen three different comets. The Halley's Comet of March 6 was very different from the Halley's Comet of March 9 and the 13th. It really was very important for us to have made three flybys." He summarized the measurements that all three spacecraft made, pointing out the value of similar measurements, measurements that were complimentary, and those that were unique to the Russian or European spacecraft. He also pointed out several gaps in coordination.

"But after all, I must say that the science was really great. Now, after many sleepless nights for the younger guys, we must part with the comet. We feel a real nostalgia in parting with the comet, but I think the comet brought with it a spirit of cooperation and friendship that will last for much longer than the next apparition of Halley's Comet."

What does the future hold for Giotto? For the time being, Giotto will be placed in "hibernation mode," pending a full assessment of its remaining capabilities. But for the long term, a week after the Comet Halley encounter, Giotto again fired its rocket to target the spacecraft for Earth flyby in July 1990.

Richard Berry followed Giotto's encounter with Comet Halley from ESA's Europaischen Weltraumoperationzentrum (ESOC) in Darmstadt, West Germany. ASTRONOMY thanks the personnel of the Giotto project, the European Space Agency, and its Service Presse et Publications for their cooperation, and the Novosti Press Agency, Tass, and Intercosmos, the Russian space agency, for providing information on the VeGa-1 and VeGa-2 missions.

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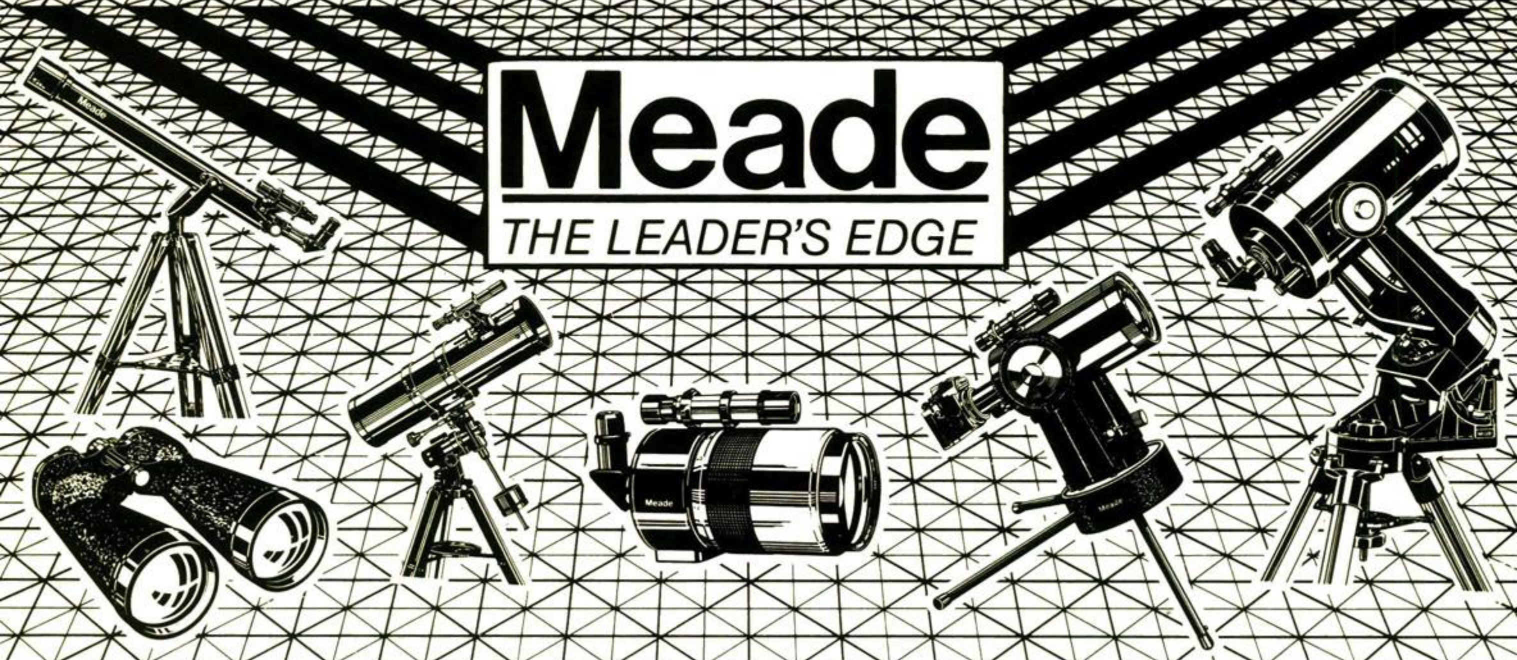

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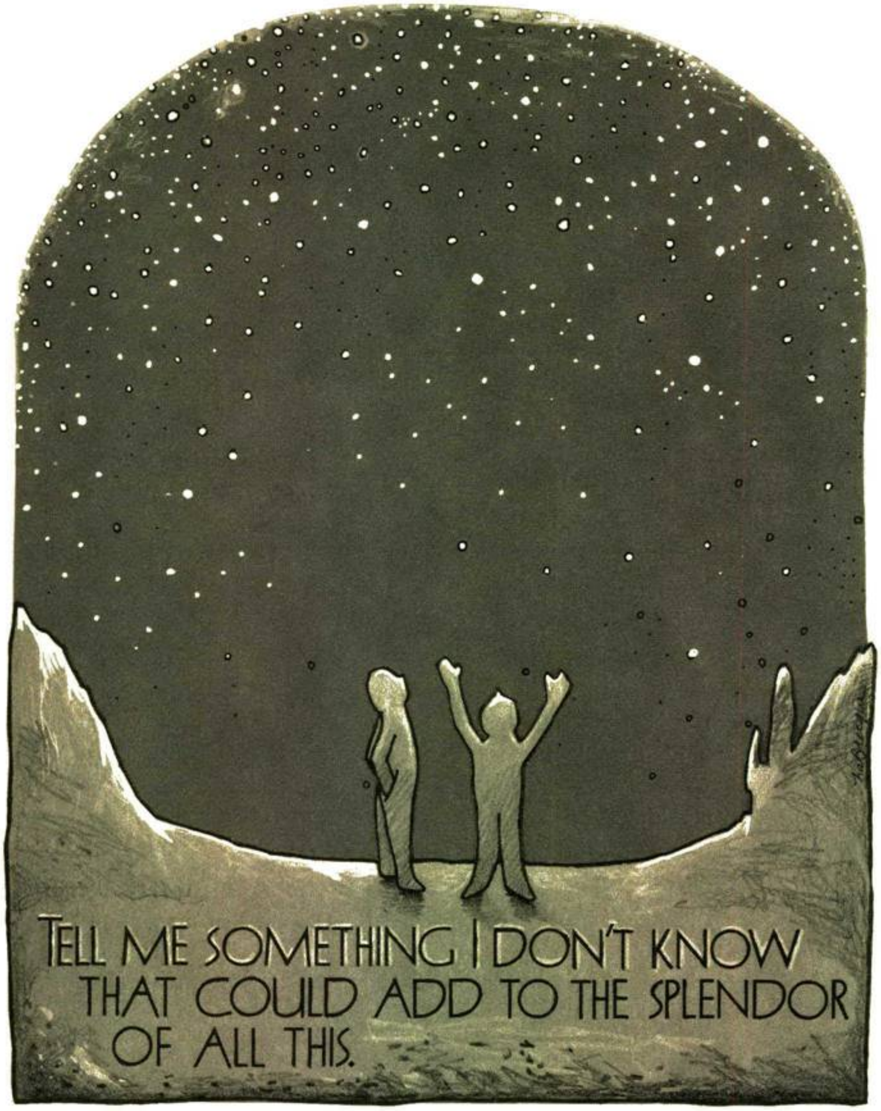
TELL ME SOMETHING I DON'T KNOW THAT COULD ADD TO THE SPLENDOR OF ALL THIS.

The Mystery of the Night

At least once every summer, my family and I invite Fernando to go with us on one of our frequent camping trips to Mexico.

I remember one particular trip when we camped on a remote beach near Kino Bay on the west coast of the State of Sonora. After a somewhat late but satisfying fish dinner, Fernando and I ventured out into the warm night, leaving my wife Sally and young son Tom to play around the campfire.

The air was almost still and the dark sky was filled with what seemed like billions of stars. At the beach the stars always looked bright and close, so unlike their unimpressive showing in the city. Fernando said that on a clear, moonless night you could only see about 6,000 of them. But I did not believe him, even though he was an astronomer at Kitt Peak and knew the sky. As I gazed upward, it appeared as if the heavens were exploding with light. There was so much light, in fact, that my dark-adapted eyes could clearly make out the rocks and shells protruding from the sand before my unprotected toes found them.

"I love nights like this," Fernando said. "I feel blessed every time we get away to Mexico." There was not much I could add, so I merely chuckled in agreement. "I'm glad I never get tired of looking at the sky, considering all the time I spend peering through telescopes," he added.

We stopped walking and I played with a stone between my toes. "Isn't it different here in Mexico," I asked, "when you're not working, not studying individual stars and analyzing their light? What is the advantage of being so methodical with the sky? Don't you think that makes it less special and mysterious for you than it is for me?"

"I suppose that's what people think — that astronomers get tired of looking at the sky because we see so much of it and think about it constantly. Or maybe you think that since we study it all the time, we lose perspective on how beautiful it is." He laughed to himself as though this were some private joke I wouldn't understand, then continued. "I've always thought that my appreciation of what's up there is heightened by what I know."

There were times when I felt Fernando got carried away with his knowledge, so I didn't think twice about challenging him on this point. "Give me a for instance," I asked. "Tell me something I don't know that could add to the splendor of all this." I swept my arm grandiosely across the sky, feeling I had trapped him with a dare to which he could not possibly respond.

Fernando was silent for a long moment before he spoke. "Okay, I'll tell you something you probably don't know about the most obvious thing we're seeing right now."

"What's that?"

"You tell me, Bob. What's the most obvious thing about the night sky, either here or anywhere else?"

I felt it was some kind of trick question, so I hesitated with my answer. "The stars, of course. What else?"

"No. Even more obvious than that."

"What's more obvious than the stars on a clear night?" I asked, somewhat confused.

"That it's dark," he answered.

"So what's the big deal?" I responded. "Everybody knows it's dark at night."

"True," said Fernando. "But not

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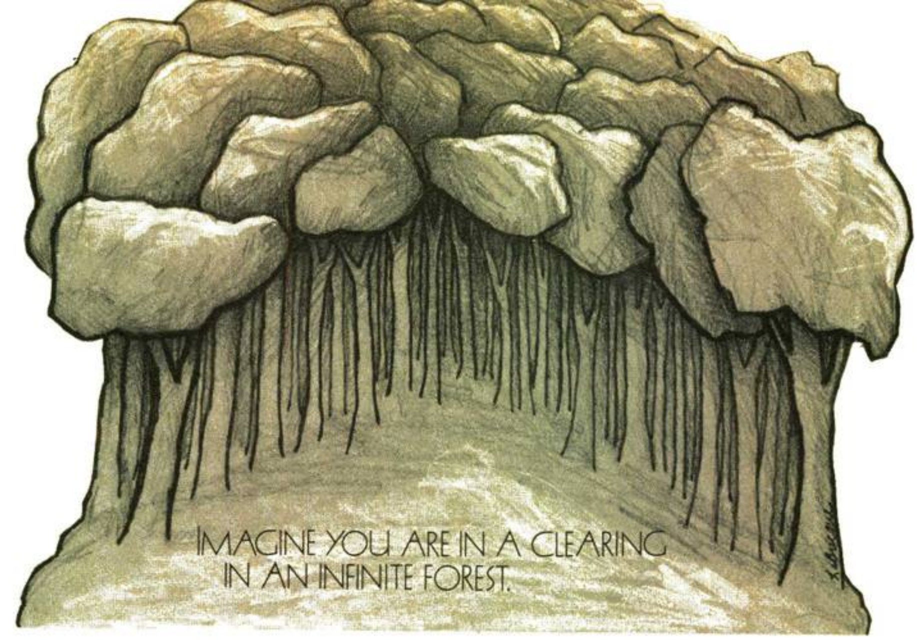
IMAGINE YOU ARE IN A CLEARING
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everyone appreciates the mystery of it. You'd probably say it's dark at night because the Sun is on the other side of the Earth."

"Something like that," I replied cautiously.

"I guess this must sound silly to you, Bob, but it really is an interesting question. Certainly the absence of sunlight at night causes it to be dark. But so does something else without which night would be as bright as the surface of the Sun. The darkness of the nighttime sky tells us something fundamental about the most distant reaches of our universe."

"Right," I said mockingly. "Sometimes, Fernando, I wonder how you can stand hearing yourself make crazy statements like that. I don't have any idea what you're talking about."

"What I'm talking about is this. Imagine that there are an infinite number of stars populating the heavens, a world without end in all directions."

"Okay," I said tentatively.

"That means that wherever we look, we would eventually see a star."

"I guess we would, so what?"

"Well, if we see the surface of a star in every direction we look, then the sky would be blazing with a light as bright as the surface of the Sun."

"Wait a minute, you lost me there."

"Well, let me suggest a different way of looking at it that may help. Imagine you are in a clearing in a deep forest, an infinite forest, in fact. From where you stand, you look out in all directions and see trees. No matter which way you look, you see tree trunks blocking your view of any clearings beyond. Even if all the trees had skinny trunks, they would overlap one another and look solid because there are an infinite number of them."

"So all you are saying is that if there were an infinite number of stars, I wouldn't see past them to the darkness beyond?"

"Yes, that's it!"

"I still don't completely understand. What if the star I'm looking at is so far away that I can't see it?"

"That's not as big a problem as it seems. Just because you can't see the tree trunk that blocks your view in a particular direction doesn't mean that it isn't there. The result is still the same — solid wood all around. If there are an infinite number of trees, you can't see past them; and if there are an infinite number of stars, you can't see past them either."

"My head's swimming, Fernando, but I think I understand what you're saying. So there can't be an infinite number of stars in the universe because it's dark out at night?"

"That's right. It's that simple."

"But I thought the stars ended at the end of our galaxy, so what's the big deal?"

"You're right, Bob, but beyond our own galaxy there are many other galaxies and I could make the same argument about them that I just made about the stars. If there are an infinite number of galaxies in the universe, then we wouldn't be able to see beyond them to the void. The fact that it's dark out means the galaxies don't go on forever."

"I see, just replace stars with galaxies and the rest of the argument remains the same. So I take it we don't have any direct evidence that the galaxies end somewhere, way out there?"

"That's true. We see galaxies to the very limits of our telescopes with no end in sight. But, in fact, the galaxies don't even have to extend to infinity to make a brighter night sky. There only have to be enough of them to overlap with each other in all directions to fill in all the gaps in the darkness. Once that is done, any galaxy beyond that point would not be visible to us. But since we know the sky is dark, we also know that the galaxies in our universe simply aren't extensive enough to crowd together and produce a bright night sky."

"That's pretty clever," I remarked. "Did you think that up?"

"No, of course not. I don't really know who first had these particular thoughts. Ed Harrison of the University of Massachusetts has traced the history of the dark-sky question back to Johannes Kepler,who studied it in the 1600s. His conclusion was that the universe could only contain a finite number of stars because of the dark night sky.

"In the 1700s, Edmond Halley sought to discredit Kepler's argument by the same point you made earlier, that extremely distant stars or galaxies would not be individually seen so they would not contribute to the sky's brightness. It was later shown that while individual stars at great distances are certainly very faint, the collective light of all the stars at each remote distance is not negligible and in fact adds up to as much as the light from the nearest stars."

"I'm glad I wasn't the only one to get that wrong, Fernando."

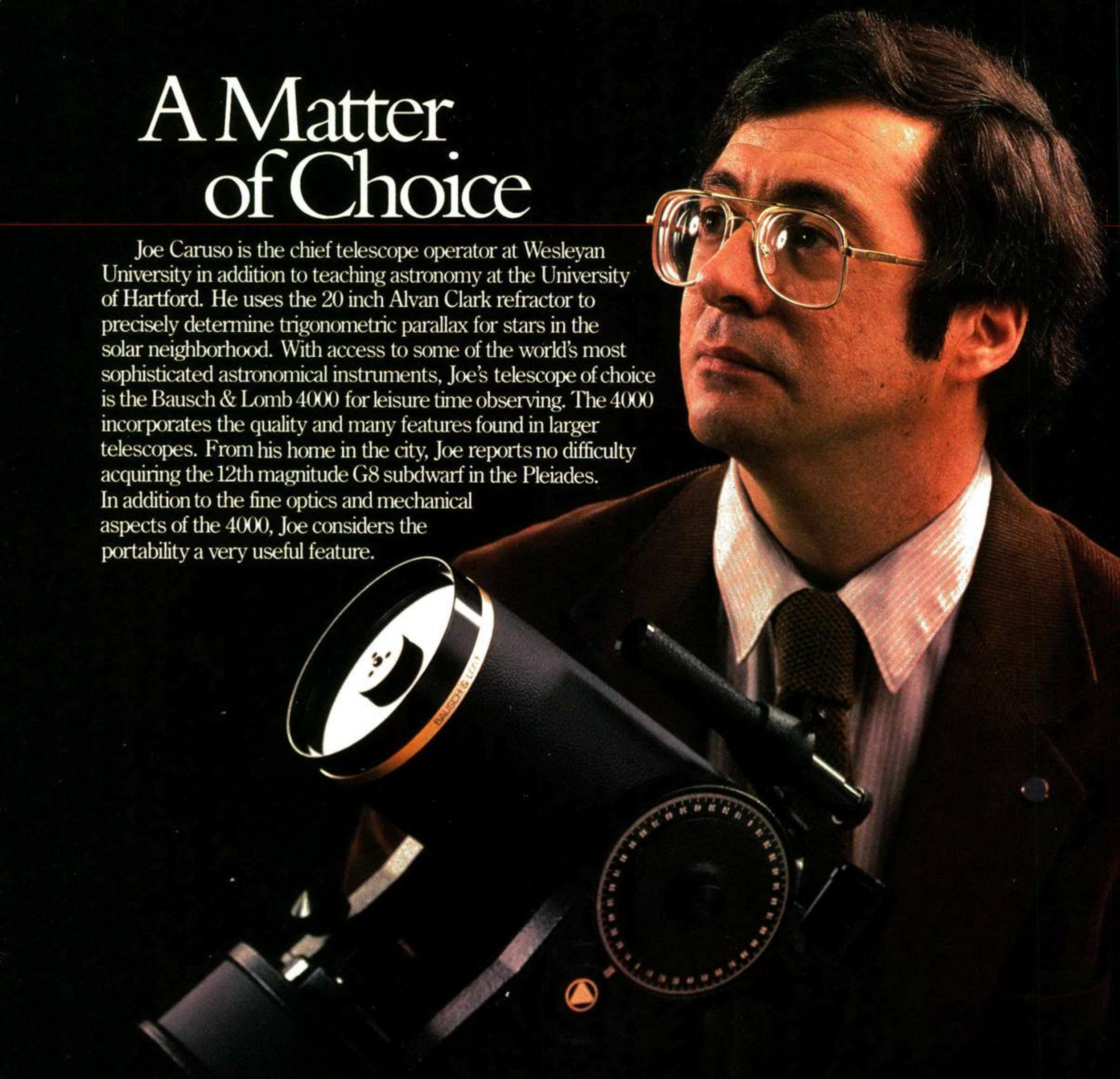
"No, Bob, You're really in very good company. In the mid 1700s, Swiss astronomer Phillipe de Cheseaux was puzzled by this, and in the 1800s, Heinrich Olbers was, too. They both sought to resolve what's now called Olbers' Paradox by suggesting that the sky was dark because there is a lot of dust or fog in space absorbing the light from distant stars and galaxies. To my knowledge, the Englishman John Herschel was the first to prove this wrong by pointing out that starlight would heat up the dust or fog and cause it to glow at the same brightness as the stars that were illuminating it."

Fernando seemed to be enjoying himself with his historical description so I let him continue, even though I already had more questions.

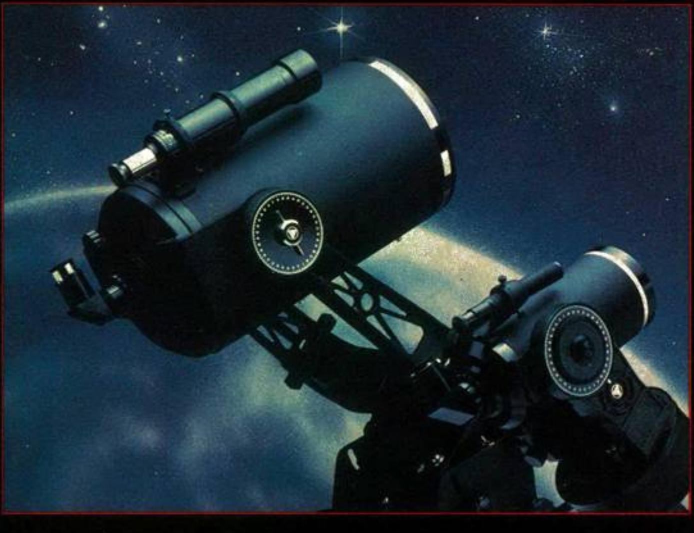
"More recently, so recently in fact that this argument still appears in some textbooks, astronomers became convinced that it is the overall expansion of the universe that 'solves' Olbers' Paradox. The idea was that with all the galaxies moving away from us, the Doppler Effect red shifts their visible light to longer wavelengths in the invisible, infrared region of the spectrum.

"However, even though most of a galaxy's light is emitted in the visible and infrared, many galaxies are still shining quite brightly at shorter wavelengths in the ultraviolet and even x-ray spectral regions. The motion of the galaxies away from us then shifts this light into the visible region so that distant galaxies are still visible to us

A Matter of Choice



Joe Caruso is the chief telescope operator at Wesleyan University in addition to teaching astronomy at the University of Hartford. He uses the 20 inch Alvan Clark refractor to precisely determine trigonometric parallax for stars in the solar neighborhood. With access to some of the world's most sophisticated astronomical instruments, Joe's telescope of choice is the Bausch & Lomb 4000 for leisure time observing. The 4000 incorporates the quality and many features found in larger telescopes. From his home in the city, Joe reports no difficulty acquiring the 12th magnitude G8 subdwarf in the Pleiades. In addition to the fine optics and mechanical aspects of the 4000, Joe considers the portability a very useful feature.



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despite their red shifts."

"Why is it called a paradox?" I asked.

"Well, it really isn't a paradox anymore, but it was thought to be in the 19th century because back then everyone was convinced that the universe had to be infinite, filled with an infinite number of stars. The argument we've been discussing proved the idea wrong."

Up to that point I had been so consumed with thinking about Olbers' Paradox, infinities of stars, skinny trees, and the rest that I had left my body on the beach while my mind considered it all. Now I was back in my body, staring at the sky and seeing it in a very different way than before. I was able to envision countless galaxies beyond the bright stars, but I had also become more aware of the darkness than ever before.

I shivered, even though the night was far from cold. Somehow knowing that the stars and galaxies must end somewhere caused me great uneasiness, as if the universe were a far colder place than I had imagined a few minutes before. A universe in which the darkness overwhelms the light.

"What's the matter, Bob? You're not usually at a loss for words."

"I don't know, Fernando, I just don't think I believe you about all this."

"Well, it isn't an easy concept."

"No, I didn't mean that. I think I understood what you were saying, your argument and all, but I just don't see how it could be right."

I stopped short and the night became very quiet. I felt as if Fernando must be annoyed with me but then he said, "Okay, at what point did you figure out that the argument couldn't be right?"

"At the very beginning, I think. I don't believe I ever really thought the universe could be limited in some way. It seems like there must be lots of reasons the light from those distant galaxies wouldn't make it to us. So they are really out there but we just haven't seen them yet." There was something that just wasn't clicking for me, but I couldn't put it into words.

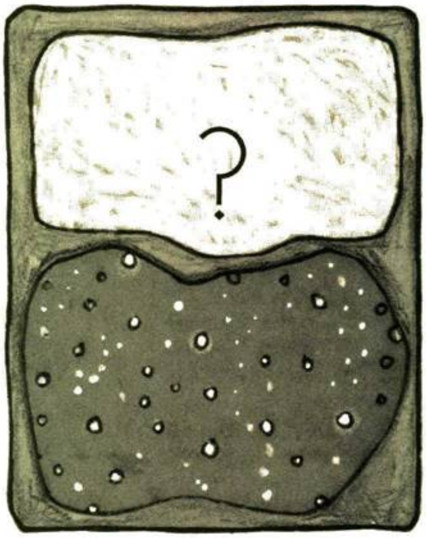
"Bob, you've hit on something I've forgotten to tell you about Olbers' Paradox. I remembered it when you said that perhaps the galaxies are really out there but we just haven't seen them yet. You see, light moves at a very high but finite rate of speed so any light we see coming from distant stars or galaxies takes a long time to get to us. As we look farther out into space, we look farther back into time. For example, take that bright star Vega there. It's about twenty-five light-years away from us, so the light we see coming from Vega left there twenty-five years ago."

I stared at the tiny, twinkling, blue-white dot he called Vega while trying to comprehend such a distance. Then Fernando turned around toward the east and pointed into the sky.

"Can you see that fuzzy blob jutting up from the two stars in a line over there?"

"Where?"

"Over there." He came and stood beside me, directing his arm toward a spot in the sky where I saw a tiny, faint cloud.



Fernando whispered to me, "That tiny spot of light is 2.5 million light-years away. It's an entire galaxy, the nearest one to us that we can see from the Northern Hemisphere. The light from that spot is the oldest light we can see with the naked eye. It's as old as the saber-toothed tiger, which was alive on Earth when the light we see tonight coming from that galaxy started on its way to us."

"Why is it so faint?" I asked.

"Because it's so far away. There is enormous energy coming from that spot, the light of 100 billion Suns. But because of its distance, by the time that light gets to us it's been spread out and diminished by an enormous amount and ends up as a faint speck to our eyes."

One hundred billion stars per galaxy, I thought. Why that's twenty stars for every person on Earth. Maybe I should pick my twenty stars before the fad catches on. Vega would be one I would choose, and Antares, the blood-red heart of the Scorpion near the galactic center of the sky.

As I looked at Antares, I remembered when Fernando had first pointed it out to me last summer and how I had been mesmerized by it ever since. Its occasional flashes of pure reds and yellows and its tendency to twinkle much more than other stars fascinated me.

I had momentarily forgotten about Fernando, becoming lost in the beauty of the night sky. When my mind returned to listening, I had evidently missed something because Fernando was already in the midst of another explanation.

". . . It is, of course, much more spectacular, even through a small telescope. But M-31, the Andromeda Galaxy as we call it, is the nearest spiral galaxy in space. All the others are farther away and too faint to see with our unaided eyes."

"But how does this relate to Olbers' Paradox?"

"Oh, yeah, I got off the track, didn't I? Well, as we look out to galaxies at greater distances, we see older and older light. The farthest galaxies we can see through our best telescopes are billions of light-years away, thus they appear much younger and much earlier in their own histories than nearby galaxies like Andromeda.

"Eventually we might be able to look back far enough to see galaxies being born. If that's the case and galaxies have a finite age, then we will eventually be able to look back beyond the time when galaxies were born, before they were making any light. A finite age for galaxies would also produce an edge to our cosmic forest. So a dark night sky can also mean that there was a time before any luminous objects *like galaxies existed* in the universe."

"I like that explanation for the darkness a lot better than a universe which is finite in size, Fernando. Maybe I like it better because all things on Earth are born and you've told me that stars are born, so why not galaxies, too, since they're made up of stars. They should have beginnings *and* endings for that matter. Have you seen a galaxy being born, Fernando?"

"No, I don't think anybody has seen that yet. Our telescopes just aren't big enough or perhaps we aren't clever enough to know what we're looking at. We do see extremely distant objects called quasars, but whether they are related to the births of galaxies is not yet known. Someday maybe we'll know."

From the tone of his voice I imagined seeing a twinkle of excitement in Fernando's eyes, even though I could barely make out his silhouette in the darkness.

"So the dark night sky tells us that our universe is finite in either space or in time. I vote for the universe where births occur," I mused.

"Your instincts are good, Bob. A universe with a finite age is the modern *resolution to Olbers'* Paradox. Astronomers now believe that our entire universe was created in a giant explosion referred to as the Big Bang some 15 or

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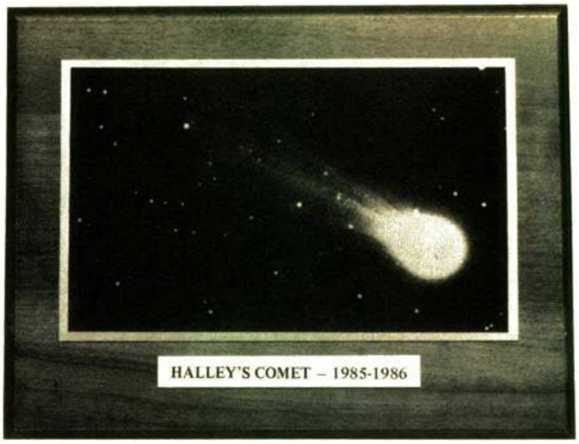

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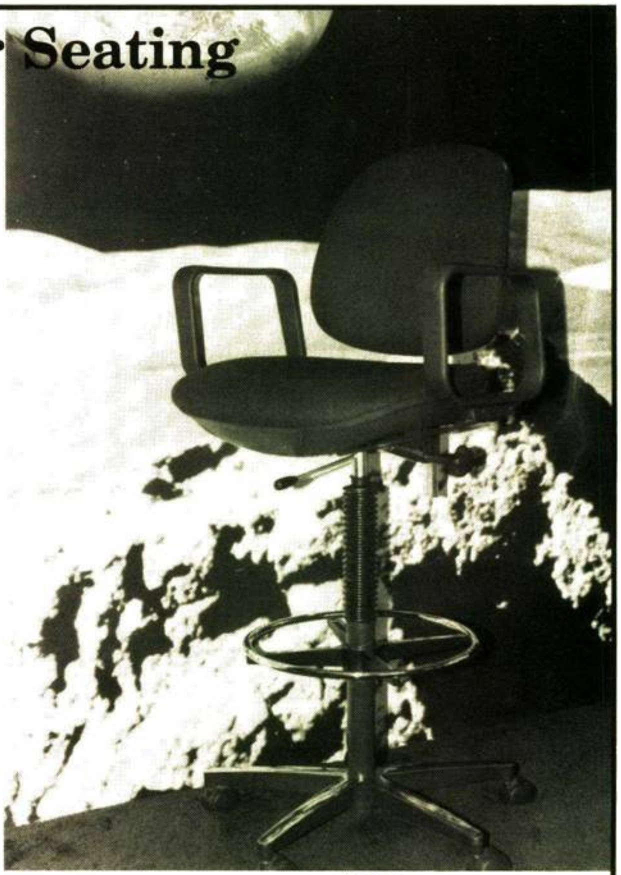

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20 billion years ago. That certainly places an upper limit on the age of galaxies; they can't be older than that."

"But since it's dark out at night, we know galaxies aren't that old?"

"Exactly. And since we know pretty accurately how far apart galaxies are situated in our universe, which is the density of our cosmic forest, we can calculate how far out in space or how far back in time the cosmic forest would have to extend to have all the galaxy images overlap one another.

"It turns out that galaxies are distributed so sparsely in our universe that the oldest possible light is billions of times older than current estimates for the age of our universe. So given a large enough telescope, we should be able to see beyond the limits of our current universe, right back to the birth of the galaxies and close to the origins of the entire universe."

"So the universe is too young to have a bright sky all around! I like it, Fernando. It sounds right to me."

"That's a good way to put it, Bob. Yes, our universe is far too young for there to be enough visible galaxies to block the darkness of the void. Maybe if our universe expands forever and if galaxies last long enough, there might be a time in our distant future when the universe will have grown older than the time of oldest possible light and the night sky will slowly become brighter. I'm glad we don't live in those times. I'm glad the universe is young for us so we have the night sky and can see all these wonderful stars and galaxies."

I don't recall how long we stood there in the darkness, not saying a word. But I do know that we were both looking at the sky, seeing it as we never had before. Now I felt quite differently about the darkness of the night, be it this glorious Mexican night or any night, anywhere, anytime, from now on.

I marveled at how the simple, obvious fact that it is dark out at night could be so esoteric, so rich in meaning. I wondered what other simplicities in our world I had overlooked, what other truths might be within my grasp. Again Fernando's voice called me back to a more human level of awareness.

"I'm getting a little chilled. What say we walk back to the fire and warm up? I've got a bottle of Cuervo stashed in my knapsack that will help take the chill off, too."

I laughed and accepted his offer with a pun, "Why not, Fernando? After all, the night is young."

— *John Stocke*
Boulder, CO

Rediscovering the Wonder of Singapore Nights

Being born and raised 1°20′ north of the equator, it isn't unusual that I didn't get to see Polaris until I was thirty-one years old.

My earliest memories of childhood, when my father was still alive and we always had a dog underfoot, go back to seeing Orion from our backyard. My brothers and I would tumble onto a large woven mat, lie down next to my father, and gaze at the Hunter.

Yet over the years, I forgot the stars. They were there, like rain and clouds and city traffic, but they only formed a backdrop for my real activities. I worked at journalism and advertising, fell in love (several times), got married, and finally joined the English department of a university. From time to time I would look up on a clear night and say, "Oh, how nice, Orion is still there."

Of course Orion was still there.

In Chinese mythology, however, there *is no Orion*, but then we weren't just any Chinese family. We were the wave of our country's future: English-educated children in a multi-racial country, the fledgling Republic of Singapore. My father would point out the easiest constellations using the western tradition of naming, mispronouncing "Betelgeuse" over and over again. He was a high school teacher who read Latin and English poetry, and who disapproved of the superstitious outlook older Chinese had about the heavens.

Still, he couldn't prevent his children from absorbing many of these superstitions. His own mother taught us that we mustn't point at the Full Moon or we would find half our ears missing when we awoke the next morning. I remember being terrified by this spell-like curse until I was about ten years old. Then, one bold and unprecedented night, I took my destiny into my own hands and pointed at the Moon with one rebellious finger for a full minute, shaking a little with nervousness. The first thing I did the next morning was to carefully feel for my ears. But — wonder of wonders! — they were intact. This momentous incident marked the turning point: I would trust Western science from now on and forsake Eastern mythology.

The next time there was a lunar eclipse, I didn't join the other children of the neighborhood in banging on pots and pans, making loud noises to frighten off the great dog — some say dragon — who had swallowed the Moon. *I* knew there was no mythological animal swallowing anything; I had learned about eclipses and the lunar phases from my science teacher at school.

However, there was one particular piece of mythology that continued to impress me. This was the tragic love story of the cowherd and the weaver, a pair of star-crossed lovers to rival Romeo and Juliet. The legend was that they were parted by jealous gods because of their mutual passion and exiled to opposite regions of the sky, with the Milky Way forming an impassable barrier between them. As all such stories go, however, the lovers' lonely exile is pardoned for one day each lunar year when they can cross that terrible divide and be together for a brief time before separating again. The lovers are, of course, the stars Vega and Altair, on each side of the Cygnus region of the Milky Way.

The feeling of wonder and awe from those early days of gazing skyward created a sense of kinship with the stars that never entirely left me. But in my teens and twenties I was busy with other things and missed what I now recognize as excellent dark-sky opportunities when I lived in Hawaii and camped out in the outer islands. If you have never seen a moonless night on a deserted beach on Kauai, far from the lights of any town or village, you have no idea what a dark-sky site can be. Without a flashlight, visibility is limited to about six inches in front of your nose, and the only sense that works is your hearing, which you know from the 15-foot waves pounding on the shore.

By this time, sad to say, I could no longer recognize any constellations but Orion. And even he had deserted me. Three years ago, when my husband and I came to the United States to pursue graduate degrees, I scanned the skies in fall and summer, but Orion was nowhere to be found. When he was visible in winter and early spring (which are the same dreary season in upstate New York where we currently attend Cornell University), we huddled indoors with the heat turned up.

This all changed dramatically last year. It was summer. The skies were magnificently ablaze with a million points of light and the Milky Way was a distinct band of glowing haze. My friend Sam announced that it was time we learned the constellations. He was tired, he said, of looking at the sky and not being able to say anything more intelligent than a respectful "Wow." I wholeheartedly concurred.

We would make the imaginative leap to see mythical heroes and creatures in the unlikely lines between the tiny lights until we stamped them

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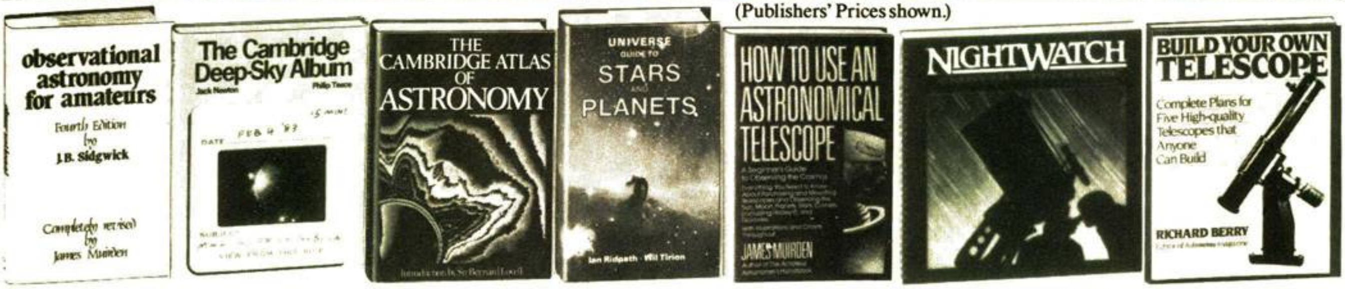
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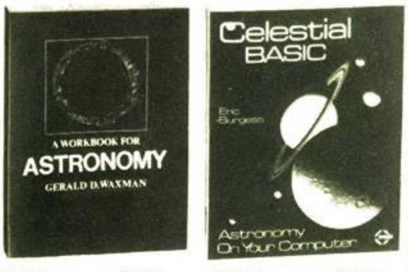
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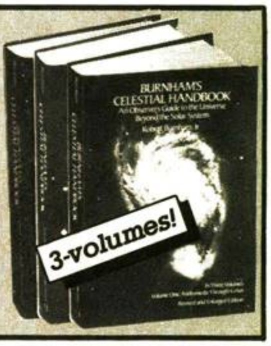
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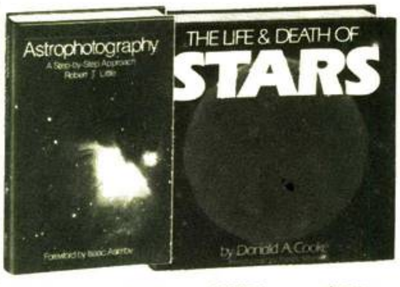
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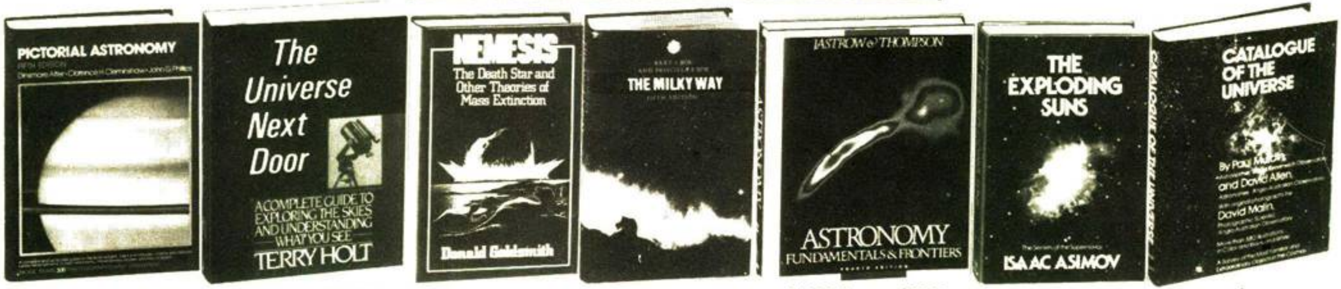
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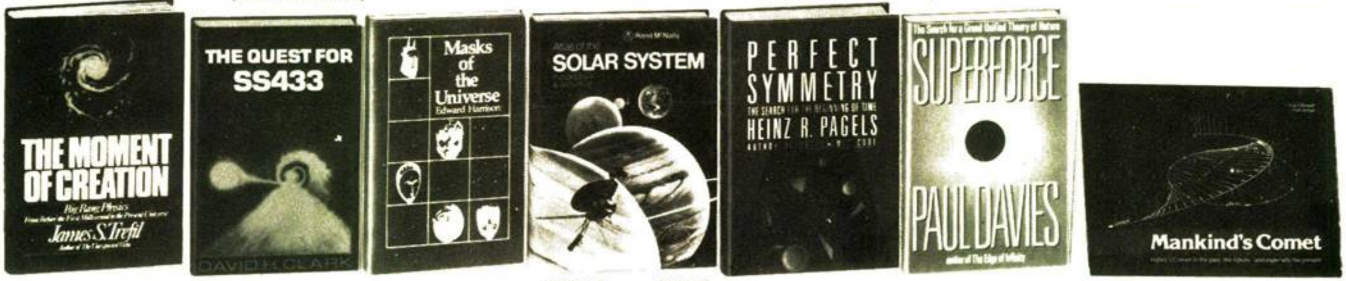
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on our memory. We would stop being among the heathens who complained that Cygnus didn't look like a swan. *We* would join the elect who could see the swan flying southward.

So, while our reluctant spouses lurked inside, Sam and I sat down on the grass in his backyard and drew lines across the sky all night long. The Dippers were childishly easy. Draco escaped us for an hour, so we were exhilarated when we finally pinned down the slippery dragon. We kept losing Hercules each time we took our eyes away to check something else and would re-draw him either too large or too small.

As Sam and I grew more successful, we also grew bolder and made up our own pictures in the constellations. Sagittarius was a glittering ice palace in the frozen southern regions and Lyra was a geometry diagram from high school math. We were happy children again, taking turns rehearsing the patterns for each other, like misers counting and recounting their gold. We were now the proud owners of the sky.

Many more nights followed that first one, and I studied the new constellations as they came into view. I sent away for star charts and books on astronomy, then waited with impatience for them to arrive. I raced through accounts of cosmology, black holes, sub-atomic particles, quasars, and the problem of the missing mass.

I bought my first copy of ASTRONOMY and carefully scanned the ads for telescopes and accessories. When I thought I had understood the technical data, I ran up long-distance phone bills discussing the relative merits of various telescope makes and models with manufacturers and dealers all over the country. Finally, crossing my fingers and hoping that I had made a sensible choice from the selection I could afford, I placed an order with a California mail-order dealer for a 6-inch reflector.

It arrived; it was beautiful.

Luckily for me, my brother was visiting at the time so he helped assemble the scope. Manufacturers only send you the most basic instructions on how to put your scope together. They don't tell you what to do when the heavy counterweights stick and won't slide onto the shaft. Nor do they explain how to properly collimate the optical elements that invariably get out of joint en route (not to mention that you don't have the right-sized wrench in the house). They don't teach you how to align the scope on Polaris, either, when you have difficulty just getting the mount to move in azimuth in the first place.

It took hours, but finally the telescope was set up. I live in a graduate student housing area, so neighbors passing by on their way to the laundry building eyed my scope suspiciously as I waited for the sky to get dark. When I aligned the finderscope to the main tube, sighting in on the top of a distant tree, someone hastily pulled her shades down thinking that I was aiming the instrument at her apartment.

OVER THE YEARS, I FORGOT THE STARS.

What I saw that first night through my telescope was a letdown. I was able to zero in on many stars, which were beautiful and vivid points of dancing color (it was a windy night), and to observe Jupiter and three of its moons. But I failed to see even one of the deep-sky objects I had read about. I had bought a richfield, short-focus telescope for deep-sky, not planetary, viewing and I was disappointed.

During a public viewing night the previous week, I had seen the Dumbbell Nebula through a large refractor at an observatory on the university campus. Now *that* was the sort of thing I wanted to see. Although I didn't expect to see the Owl Nebula with a 6-inch scope from a housing complex located under suburban skies, I wanted to at least catch the more prominent of the glamorous Messier and NGC objects — the great spiral galaxy in Andromeda or the Orion Nebula, or perhaps M-13 and M-15 — objects I could already see with the naked eye.

After that first session, I tried again on every clear night. But our area is legendary for its lack of clear nights. Two good nights in a week is lucky; three is incredible; one is about average. Sometimes whole weeks go by without a single undisturbed night of good seeing.

Then one night I saw them: my first deep-sky objects. After nearly two hours of struggling with stray clouds, I was exhausted and more than ready to give up. I had just read an article on the difficulties of deep-sky viewing that explained what I was doing wrong: Try higher powers, it said; keep your eyes still for six seconds because they gather light like a camera; eat something, since your ability to keep still improves if your sugar count is high.

I did all those things, but the clouds were definitely about to win out. Then, just to be a good loser, I decided to aim one last time at M-31 in Andromeda. Despite everything I had read, I was sure it would be a tiny, nearly invisible spot in the eyepiece, probably something I had already zoomed past many times in the last two hours of searching and had failed to recognize.

But it was not a tiny spot at all. It was huge and utterly lovely; exquisite beyond compare.

On that last try a smudge appeared in the finderscope exactly as the stories say it should. As I looked into the eyepiece, hardly daring to breathe — voila! — it filled the entire view: a soft, majestic oval of light that almost seemed to shimmer against the dark background sky. Three hundred billion stars, 2.5 million light-years away, the most impressive object in the Local Group, and I had seen it. Now I could die content.

My next deep-sky sighting, M-42 in Orion, was almost anticlimatic. It was amazingly easy to spot compared to M-31, pinpointed by that little line of stars my father had pointed out to me twenty-five years ago as the Hunter's belt. It, too, was breathtaking, but I felt sad that the favorite person of my childhood, the man who had mispronounced "Belelgeuse" so many times, wasn't there to see it with me.

Now I have begun. Like the rest of you who read this magazine, I will go out every clear night and find my way around the stars. It's like being a child again, only better because now you understand what you're seeing. And, as any born-again stargazer will tell you, the universe is lovelier the second time around.

I can hardly wait until my 10-inch Dobsonian arrives. I can hardly wait to return home and live at the equator again where I can watch the parade of stars that you can't see from 42° north latitude in upstate New York. Polaris, of course, will be back on the horizon, lost to me again. But with all the other riches of the sky, who needs Polaris?

Geraldine Heng
Ithaca, NY

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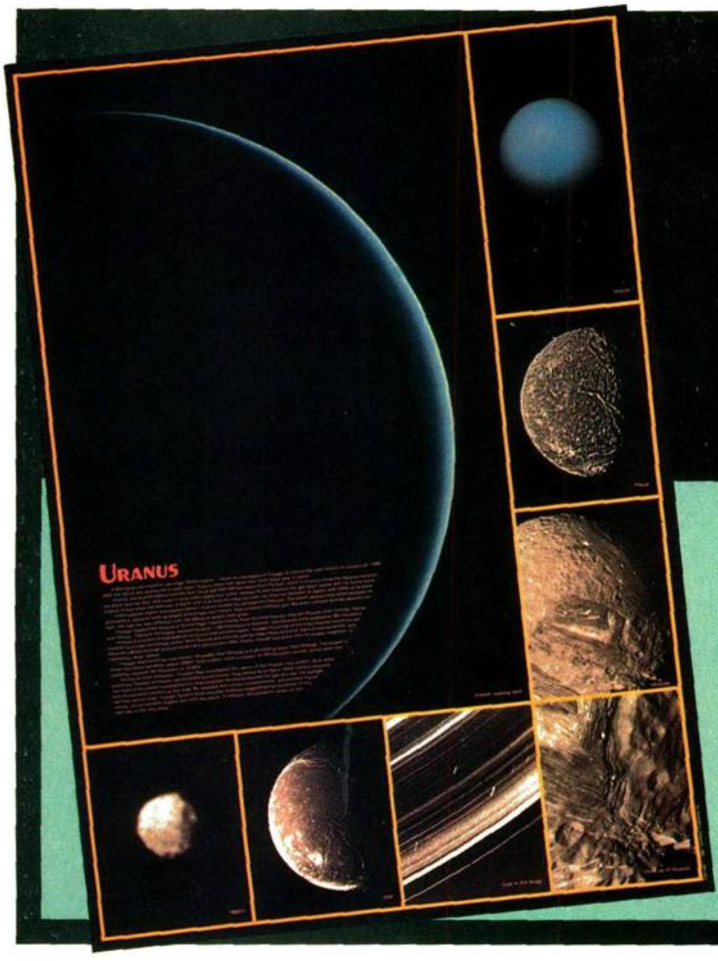

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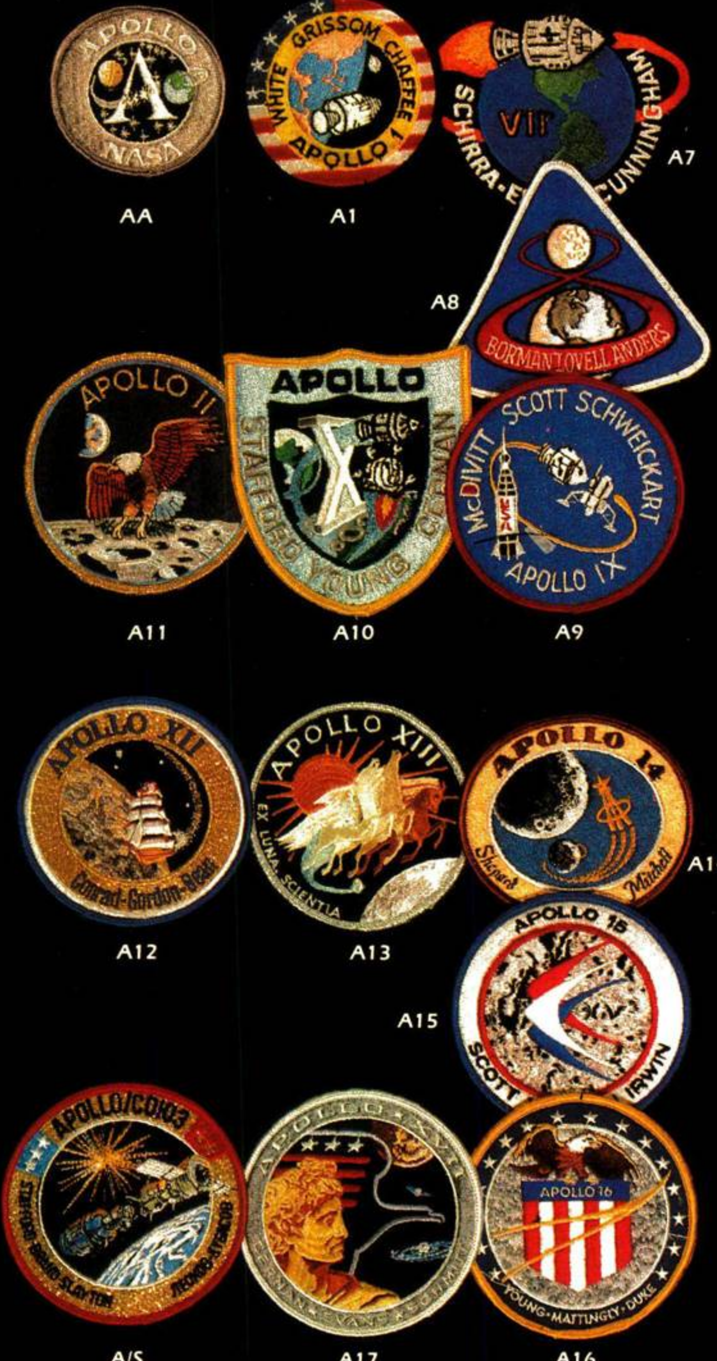
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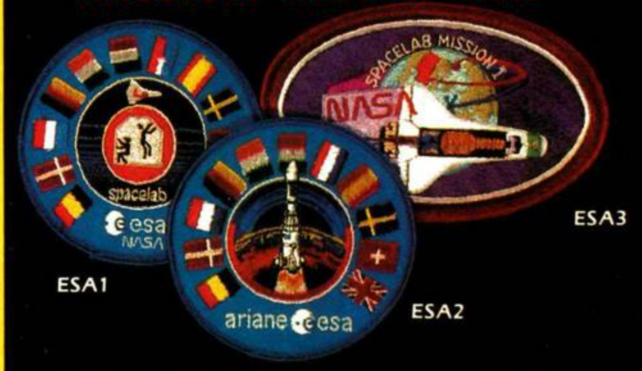
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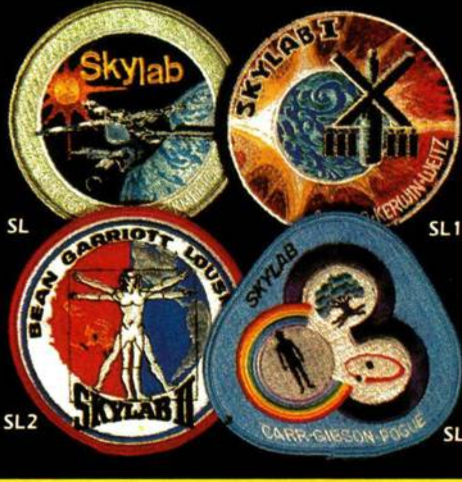
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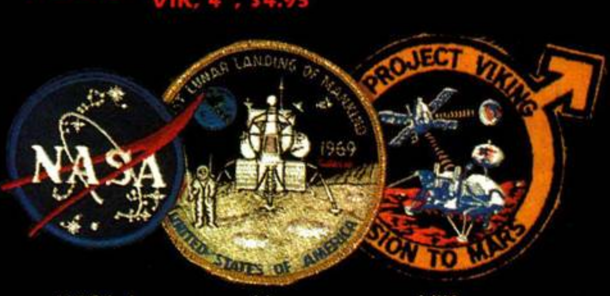
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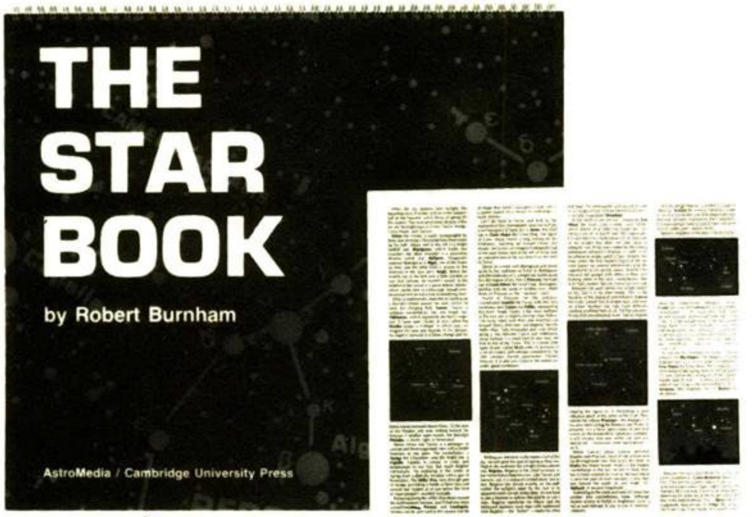

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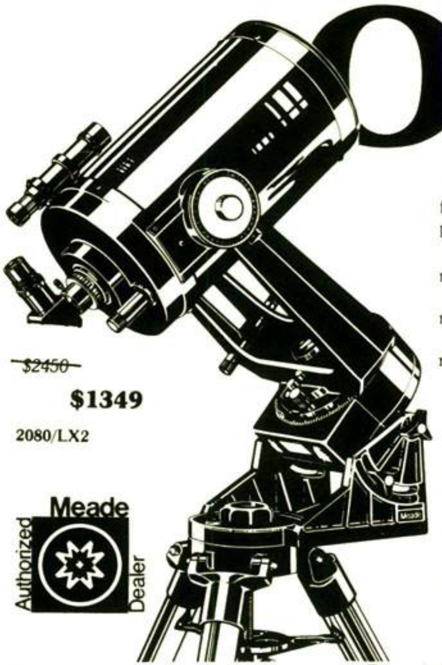

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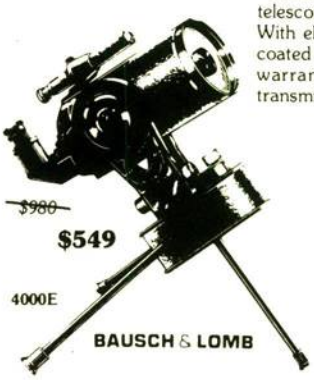

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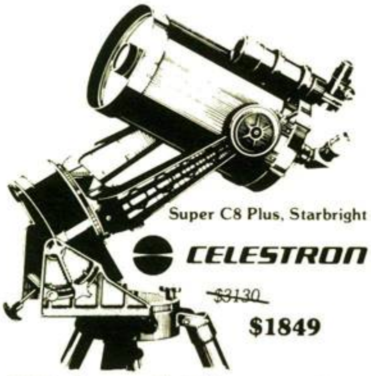

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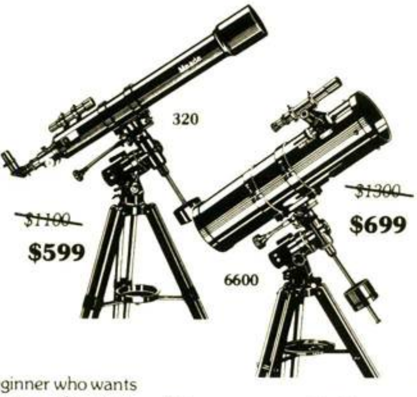

Meade 226: A good quality 2.4" altazimuth for the beginner who wants crisp and detailed lunar, planetary, and terrestrial views at a low cost. With two .965" eyepieces, altazimuth mount, tripod, finder, lifetime warranty. *$300 list*. Regularly $179, we have 17 **at only $139!**

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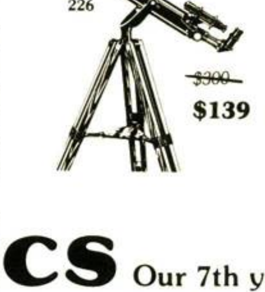

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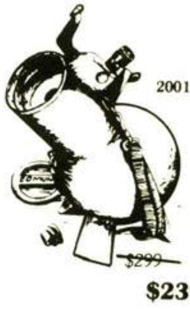

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ASTRONOMY
In Focus

Urban Astrophotography

Sir / No one questions that rural skies are superior for photographing nebulae, but how many know it's still possible to get surprisingly good results from cities and suburbs?

During the late 1970s, a photographer named Jospeh Cocozza wrote the book *Astrophotography Near City Lights* in which he described a technique of attenuating light pollution using red-sensitive 103a-E spectroscopic film and a Wratten #92 deep red filter.

More recently, many astrophotographers have combined hypered 2415 Technical Pan with Hα filters to good effect, since 2415 has finer grain than the old spectroscopic films and the Hα filter stops more light pollution than the #92 filter. Remember that both the old films as well as the newer hypered ones are heat sensitive and must be kept in the freezer until shortly before use. Then they must be processed promptly or they'll fog up. Tri-X won't do as a substitute, since it isn't very sensitive in the Hα region of the spectrum. But color slide films *are* sensitive there.

One transparent November night, I took several exposures of Orion from my backyard, which is only three miles from downtown Houston. On the best exposure (30 minutes at f/2.8 on Fujichrome 400 with an Hα filter and a 105mm lens), M-42 dominated the picture since the filter suppressed starlight as well as light pollution. But on examining the slide with a loupe, I found the nebulosity near ζ Orionis and in this nebulosity was a tiny notch — the Horsehead Nebula!

Leland A. Dolan
Houston, TX

Happy Halley Hunting!

Sir / After reading "Your First Shot at Halley's Comet" in the November 1985 issue, I had to write. Like everyone else, I too have been anxiously awaiting the arrival of the comet.

On the night of November 17, I grabbed my 7x35's and began the search but couldn't find the comet. I loaded my camera with VR1000 film and took a series of 25-second shots of the Pleiades and surrounding area through a 250mm telephoto lens. I only recorded stars.

On the 18th, I hauled out my 6-inch Newtonian, piggybacked a 50mm lens, and waited. I felt like crying when the clouds began rolling in. Fortunately, by 11:00 p.m. the sky cleared. I calmed down and took a series of photos using ASA 400 film with exposures running from 10 to 15 minutes each.

To end a long and frustrating story with a happy ending, my results were everything I had hoped for and more!

D. Mullin
Norristown, PA

Clear Skies Not Guaranteed

Sir / I felt that Edward W. Eaken's letter (In Focus, February 1986) was ridiculous. Sure, astronomers are always complaining about the weather, but let's face it, nobody can guarantee clear skies anywhere.

Last year's Texas "Cloud" Party was my first and I had a blast! I even knocked off half of my Messier certificate in-between occasional clouds. If anyone travels all the way to Fort Davis, Riverside, Stellafane, or other star parties and demands cloudless skies, he is nothing more than a self-deluded dotard.

Considering past attendances of around 500, I think the people who plan the Texas Star Party have found the best location possible. With McDonald Observatory nearby, the feeling of dark-sky observing pervades every activity. Accommodations and organization were first rate. You couldn't ask for more — except, perhaps, *guaranteed* clear skies! And if that is what Mr. Eaken expects, may I suggest that he schedule his next star party in a planetarium!

Joe Pearson, Vice President
Oklahoma City Astronomy Club
Edmond, OK

Another Ogre?

Sir / Bill Katz's recent article ("Chasing the Ogre," January 1986) reminds me of an observation I made at Stellafane in 1983.

While watching for Perseid meteors, I was surprised to see what appeared to be a point meteor within the head of Draco. During the next 15 minutes, the flash appeared two more times in the same position. This observation was puzzling at the time, but after reading Katz's article, I now believe I may have seen another of the hypothetical Optical Gamma Ray Emitters.

The location of the flashes was within a 1°-radius circle centered on RA 17h 43m, Dec 53.7°. *Sky Atlas 2000.0* shows three stars within this circle, the brightest of which is about 6th magnitude.

In each instance, the flash lasted about one second and reached a magnitude of about 1 or 2. The sky conditions were very good at the time.

I find it astonishing that a naked-eye celestial phenomenon may have gone unnoticed until recently. I look forward to hearing more about this subject.

Richard Sanderson
Monson, MA

Meteor Weekend

Sir / For the past several years, European meteor observers have been getting together one weekend a year to meet each other and discuss meteors. This event, organized by the meteor section of the Vereniging Voor Sterrenkunde (VVS), has become known as the International Meteor Weekend. Its aim is to stimulate international cooperation among meteor observers through lectures, discussions, and informal talks.

Another such meteor weekend is planned for October 3 to 5, 1986. The meeting site is a castle in Hingene, Belgium, a village 15 kilometers from Antwerp.

We are proposing that an international meteor camp be held during the summer of 1987 at Puimichel in the Haute Provence of France. Successful meteor observations have been made there since 1984, one of the most impressive being the Perseid shower in 1985 when 250 meteors were photographed and over 16,000 recorded visually during two weeks by twelve observers.

For information about these events, contact the VVS Meteor Section c/o Paul Roggemans, Dellingstraat 25, 2800 Mechelen, Belgium.

Paul Roggemans
Mechelen, Belgium

Night Launch

Sir / I received my copy of the March 1986 issue about three days after the Challenger tragedy. I was very pleased and impressed to see that ASTRONOMY magazine deems the Space Shuttle program important enough to dedicate seventeen pages to it.

I would, however, question the annotation for the photo on page 4. This photo is identified as the lift-off of Mission 61-B. Mission 61-B used the Atlantis orbiter and was launched at 7:29 p.m. — a night launch. The photo appears to show a launch on a bright and sunny day. If this is indeed Atlantis, then it would have to be Mission 51-J, this shuttle's maiden flight and a Department of Defense mission.

Carleton T. Bailie
Orlando, FL

— You are right, and thanks for the correction. We trust that our readers will understand that the March issue was prepared in anticipation of a triumphant year for the Shuttle program with immense payoffs for science.

Sacrifice an Elaborate Hoax

Sir / I am an Oklahoman and a long-time member of the National Capital Astronomers of Washington D.C. I spent considerable effort in 1985 to get to the bottom of the reported near-sacrifice of a virgin by a group of religious fanatics near Aline in Alfalfa County, Oklahoma in 1910 (Forum, March 1985).

The alleged victim was Miss Jane Warfield, whose age was variously given as 16 and 19. The sheriff who came to the rescue was a "Sheriff Hughes," said to be from either Alfalfa or Dewey County. The leader of the religious sect was a "Henry Heinman."

The real facts, however, are these: No Jane Warfield is listed in the Alfalfa County index to the 1910 census. The sheriff of Alfalfa County in 1910 was D.A. Hughey, whose son never heard the story. The sheriff of Dewey County in 1910 was J.A. Mukey, and no check of court records there has turned up any evidence to support the story. The sheriff of Major County, where the incident was supposed to have taken place, was Lewis Burwell.

In brief, there never was a "Henry Heinman" nor a "Jane Warfield" nor a "Sheriff Hughes" according to extant records.

When the *Cherokee* (Oklahoma) *Republican* ran the story on May 27, 1910, the editor said that "not a word" of the harrowing story was true and identified the hoaxer as Edgar Marchant of Aline. Marchant (1858-1919) was a successful lawyer, newspaper editor, and publisher of the Aline *Chronoscope*. The *Chronoscope*, incidentally, did not carry the virgin-and-the-comet story.

In researching this story, I was fortunate enough to meet Mrs. H.L. Elliott of Aline who knew Mr. Marchant and his wife, Ellen. Mrs. Elliott, now 75, lived with Mrs. Marchant for a time and was the source of a great deal of information about the couple.

The story of the virgin and the comet will likely surface again in 2061 because it is such a fine tale. Please help establish it for what it is: a clever hoax. Writers in 2061 will no longer be able to consult with Mrs. Elliott, who is the last living link to the Marchants.

Guy W. Moore
Arlington, VA

Behind the Scenes

Staying on Top

Courtesy of Europe's Giotto mission, we've now seen that the nucleus of Comet Halley is a big iceberg, blacker than coal, that sprays water vapor and comet dust into space from vents in its surface. We know it must have a thick crust of dark material and that its surface is roughly 330° Kelvin (that's 134° Fahrenheit), courtesy of infrared sensors aboard the Soviet's VeGa spacecraft.

We examine the razor-sharp images coming down from the French SPOT Earth resources satellite, while seeing NASA's Landsat system (recently upgraded to one-fourth of SPOT's resolution) become a political football for "privatization." We hear the Russians announce an ambitious, integrated plan for the exploration of the solar system, a plan that sounds suspiciously like a selection of the best missions from the SSEC planetary exploration program that NASA can't quite seem to fund. We watch as a private company, Arianespace, grabs a significant chunk of the commercial satellite launch market while NASA actively discourages private space initiatives here.

And we worry.

For despite its enormous head start and major technological advantages, the United States could be losing its lead in space. Perhaps this is as it should be. After all, doesn't the plaque on the side of the Apollo 11 lander read: "We came in peace for all mankind"? As we watch other nations develop the capability to leave Earth and gaze back down on this big blue marble, or to launch explorations to a comet or Mars or the outer planets, are we not seeing space become the province of all mankind?

Nonetheless, it seems a shame to sacrifice our lead, not because of the competence of our competitors — though they are certainly competent — but because we lack direction and coordination in our own space program. While concentrating its brains, money, and resources on Shuttle hardware for the last ten years, NASA has postponed or cancelled one major science mission after another and demoralized the corps of space scientists who made the Pioneer, Viking, Mariner, and Voyager missions happen.

We can only hope that the soon-to-be-released report on the next fifty years in space, prepared by the National Commission on Space and dedicated to the crew members of Challenger's last flight, will provide a much-needed direction for our space program.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

Photography in Astronomy

Halley Emerges in the Morning

Only three weeks after slipping out of the evening sky toward its rendezvous with the Sun, Halley's Comet showed up again in the predawn sky, looking better than ever. Just before dawn on the morning of February 15 — less than a week after its passage through perihelion — astronomer Richard West of the European Southern Observatory at La Silla, Chile glimpsed the comet in a twilight sky.

At the time, West estimated the comet's brightness at about magnitude 3 — brighter than most everyone had hoped for — but since the sky was so bright, he couldn't be certain. The following days confirmed his estimate: not only was Comet Halley back, but it looked bigger and brighter than any time since its closer encounter with Earth in 1910.

All of the excitement over Halley's post-perihelion brightness couldn't have come at a better time. In late January, most observers had their last views of Halley. They were not exactly overjoyed with the comet's performance during the incoming leg of its journey. Most people who bothered to look at Halley declared they were happy to see anything at all.

"Most of the people who eagerly came [to view Halley] went away somewhat disappointed that Halley's Comet was not as bright as they expected it to be," wrote Gary A. Becker in the Lehigh Valley (Pennsylvania) Amateur Astronomical Society's *Observer*. "But that was unimportant. They had seen the legend, and went away satisfied that they had continued a tradition which had been established in 240 B.C. and probably earlier."

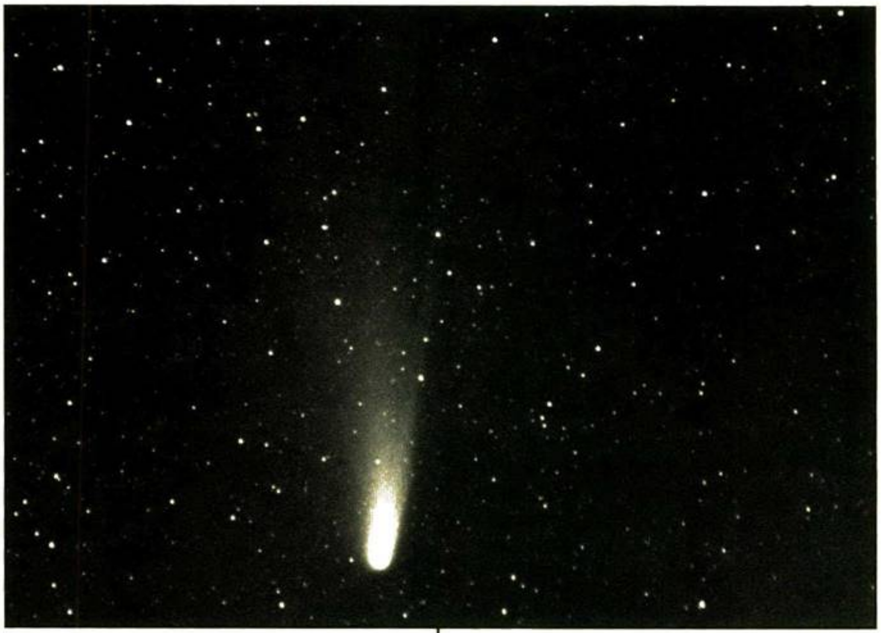
Wallace G. Pursell of Baton Rouge, Louisiana, reported that "on January 27 I got my final in-bound view of Halley's Comet from the levee at Baton Rouge. It was a race: darkness was falling about as fast as the comet was sinking into the horizon haze. It was a matter of the comet not sinking too far before the sky became too light to see it. From about 6:35 p.m. to 6:40 p.m., using my spotting scope at 22x, I was able to see a very faint nonstellar object come-and-go and come-and-go several times before it sunk too far down to be seen through the haze near the horizon."

As enthusiastic as they are, these reports and dozens more like them that were made during late January are characterized by muted disappointment and intimations of "Comet Halley, why are you letting us down?"

Enter Act Two: the reappearance of our celestial visitor during the last half of February.

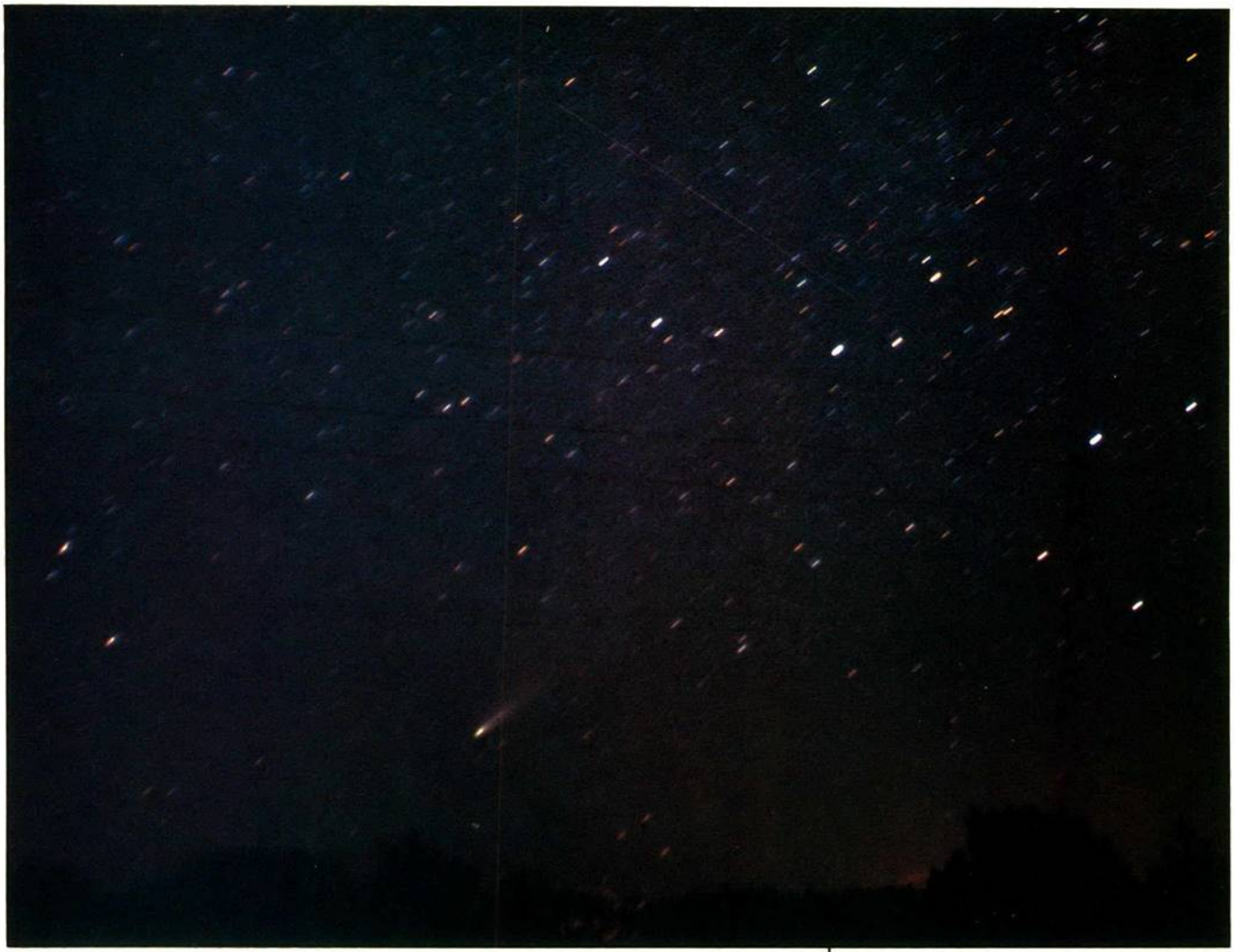
As soon as the comet was visible again in a dark sky, having passed its closest approach to the Sun and reaching a maximum level of activity, the disappointment faded. Clearly Halley's Comet was now an easy naked-eye patch of light. It was bright and detailed in binoculars, and offered what most observers deemed suitable recompense for its slightly tarnished reputation. Said veteran comet observer David H. Levy of Tucson: "It's now bright enough that it rekindles fond memories of Comet West in 1976 . . . even though it's only one-tenth as bright!"

Stephen W. Bieda Jr. of Sierra Vista, Arizona, observed Halley on the morning of February 22. He wrote: "Now that Halley's Comet has moved somewhat farther out of the twilight and now that I am unhampered by clouds, I have finally

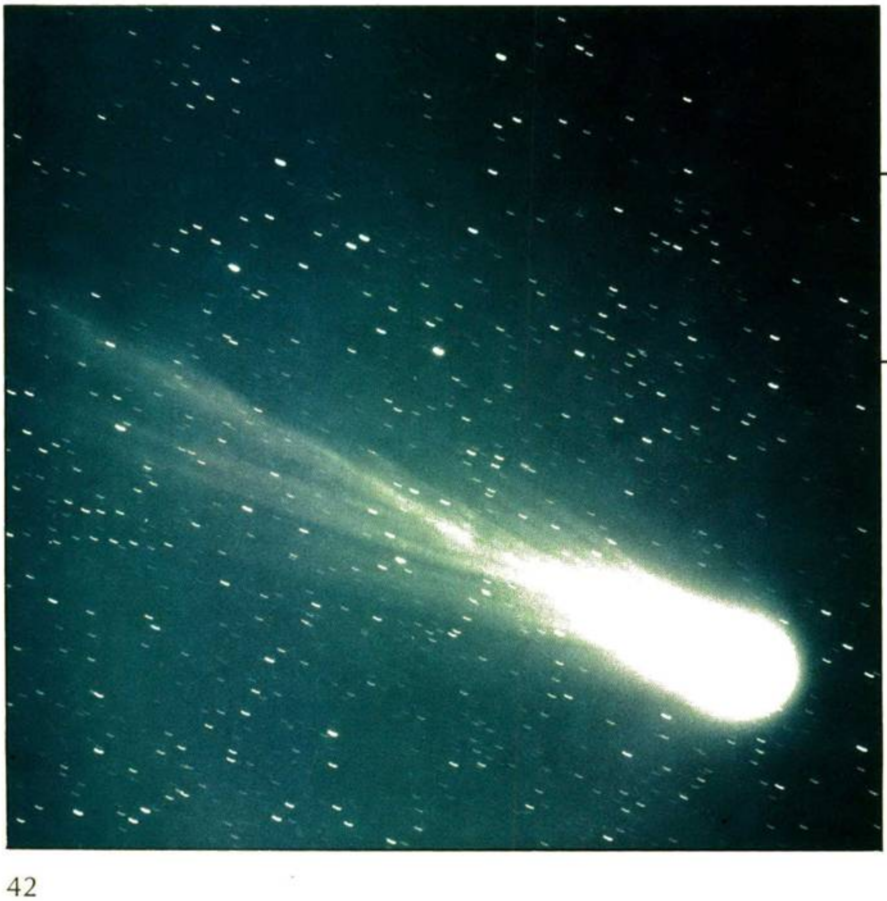


This image of Halley was made on March 8. Photo by Jack Metcalfe using a 135mm f/4 lens, hypersensitized Tech Pan film, and a 15-minute exposure.

On March 20, Halley's Comet was a 3rd-magnitude object in Sagittarius visible as a fuzzy streak with the naked eye. Binoculars revealed more than 5° of the comet's tail. This photo was made by Eron Lee, who used a 135mm f/2 lens, Fujichrome 1600D film, and a 10-minute exposure.

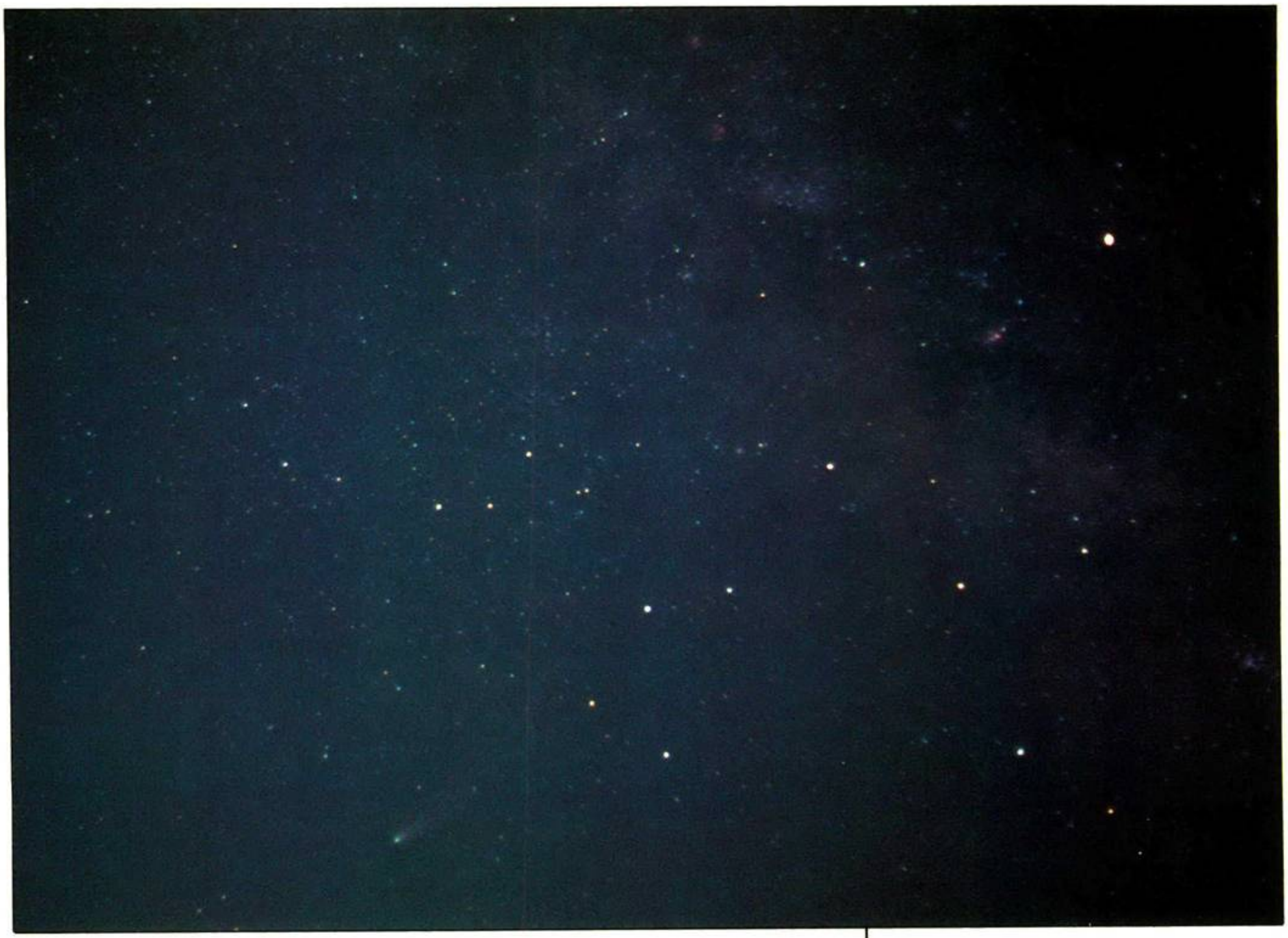


Before dawn on March 14, Halley had risen high enough for this star trail photo to record the comet and a meteor. Photo by Gene Brings using a 50mm f/1.7 lens, VR-400 film, and a 40-second exposure.

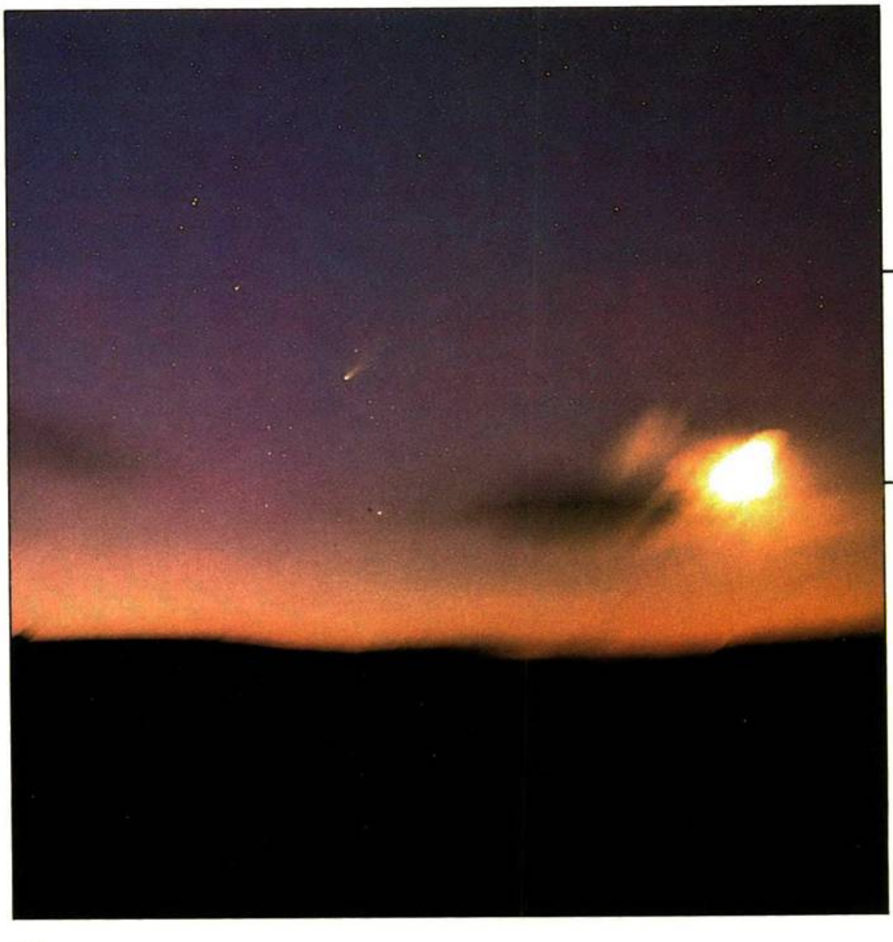


Before Halley reached perihelion in February, the comet displayed impressive detail in its ion tail. This view on January 9 was made by John W. Briggs using a 16-inch f/5.5 Newtonian, hypersensitized Tech Pan film, and a 30-minute exposure.

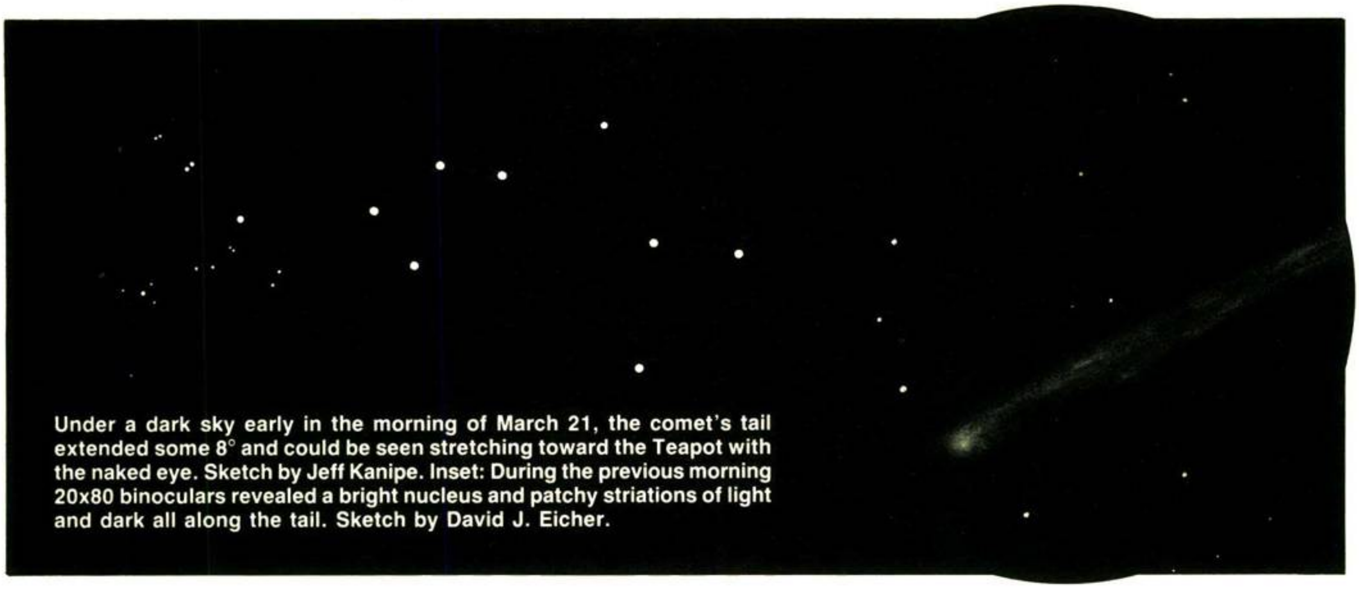
During the second half of March, Halley began appoaching the Teapot of Sagittarius and the surrounding Milky Way. This wide-field photograph shows all three objects. Photo by Chandler J. Kennedy using a 45mm f/2.8 lens, hypersensitized Tech Pan film, and a 10-minute exposure.



On March 22, Halley's tail extended some 5° toward the Teapot's handle as shown in this photo. The Sagittarius Milky Way extends through the upper right of the image; brilliant Mars lies just above and to the right of the pinkish Lagoon Nebula. Photo by Frank Brynes using a 50mm f/2 lens, 200 ISO film, and a 5-minute exposure.



During the first week of March, the waning Moon interfered considerably with viewing Halley. But the comet was visible by March 7, as this shot shows. Photo by Barney Magrath using a 6x7-format camera with 105mm f/4 lens, Fujichrome 400 film, and a 5-minute exposure.



Under a dark sky early in the morning of March 21, the comet's tail extended some 8° and could be seen stretching toward the Teapot with the naked eye. Sketch by Jeff Kanipe. Inset: During the previous morning 20x80 binoculars revealed a bright nucleus and patchy striations of light and dark all along the tail. Sketch by David J. Eicher.

been able to make an estimate of the comet's magnitude. Its head — nucleus and coma — seems to be shining at magnitude 3.1."

The next morning Barbara Wilson of Houston, Texas, saw the comet and provided this detailed account of its appearance: "I observed Halley's Comet at 5:50 a.m. from a rice field just south of Houston. In 11x80 binoculars mounted on a tripod it was a bright, beautiful sight with a wide, fan-shaped tail streaming about 2.5° away from the coma. The central condensation in the coma shone at approximately magnitude 2.5; the tail's overall magnitude was perhaps 3.5. There was a jet or stream of light pointing east toward the Sun. I stepped away from the binoculars and simply looked: Halley's Comet was distinct, fantail and all, with the naked eye."

Wilson continued, "I have been trying to see Halley since the morning of the 20th, but ground fog and clouds have stopped me until today. This morning I was startled at the comet's brightness in spite of a nearly-full Moon and considerable twilight, not to mention the fact that Halley was only 14° above the horizon. I followed the comet until about 6:10 a.m. when it had faded to a mere fuzzy ball in the brightening twilight."

In *The Meteor*, the journal of the Escambia (Florida) Amateur Astronomers' Association, Wayne Wooten described his observations during the week of February 24: "Merry, Michael, and I got up on Monday morning, February 24, to get a first glimpse of the comet. At 4:45 a.m. we spotted it in the twilight using a pair of 9x63 binoculars; it had a slight tail, about 2° long, but twilight and the nearly full Moon made the going difficult. We only watched Halley for about five minutes before dawn's early light faded it out."

The Wootens also observed it several days later. "Merry woke me at 4:00 a.m., and by the time I got to the bluffs at 4:15 a.m. Charlie Strickland, Gerald Victorian, and Robert Chamberlain already had their scopes set up and were showing about thirty folks the Moon and Saturn. No one had yet spotted the comet — there was some horizon haze to the east. At 4:30 a.m. my 9x63 binoculars revealed the comet about 4° directly below Beta Capricorni; it was still in the haze, and some of the folks who looked first weren't impressed. But by 4:45 a.m., it was clear of the haze and showing a dramatic tail in Charlie's Comet Catcher. The tail appeared some 3° long and spread out into a fainter version of Comet West in 1976. By 5:00 a.m. almost everyone had detected it with the naked eye. I estimated its magnitude at 3.5, only slightly fainter than Alpha or Beta Capricorni, as the comet rose about 8° high before twilight started fading it."

The first days of March improved the view considerably as Halley moved higher up in the sky and the Moon waned, finally disappearing on the 10th. Tom Randall of Poughkeepsie, New York, described his observation of Halley on the 8th of March: "Because there are no ideal viewing spots in my town, I traveled 16 miles eastward to Millbrook and found a perfectly unobstructed eastern horizon. The sky was crystal clear; Sagittarius seemed to jump out of the blackness as did the Milky Way, Mars, and M-6, M-7, and M-8. Not one artificial light was in sight. We had arrived at 4:50 a.m. and it was extremely cold out. The temperature was 3° F with a windchill of −20°. The wind made it very difficult to observe and take photographs. The camera froze up several times as did our hands!

"I spotted Halley at approximately 5:00 a.m. using my 8x40 binoculars," said Randall. "It appeared fairly bright and its tail was slightly dimmer than its coma. The tail pointed toward Mars. I was able to keep Halley in binocular view until 5:25 a.m. Tomorrow morning I will be right back to see Halley and hopefully get some unforgettable pictures. Is getting up in the middle of the night and standing outside in below-zero temperatures worth it? You bet!"

On the morning of March 20, I had a similar experience. Taking advantage of a rare break in the Wisconsin cloud cover, Jeff Kanipe, my father John Eicher, and I packed our gear at 3:45 a.m., then drove north out of Milwaukee toward Harrington Beach State Park, a distance of some 35 miles that would ensure a dark sky. We pulled off on a landing right on the edge of Lake Michigan. The only lights to the east were over 60 miles away. The temperature hovered around 0° F and the wind chill was reportedly −25°. To make matters worse, as dark adaptation set in we discovered that we had set up on an icy plateau several feet high complete with miniature icebergs rising up some 15 feet higher. The chill set in fast.

Jeff set up his 8-inch reflector. I clutched a pair of 20x80 binoculars. My father was astonished that he was actually standing on Lake Michigan at 4:30 a.m. experiencing a −25° wind chill. The sky was very dark. I spotted Halley with the 20x80s and it was a completely different sight since I last viewed it in January. The coma shone at magnitude 2.5 and showed a strong central condensation; the tail was relatively faint but extended over two binocular fields — some 8°! The tail showed kinky striations of dark material and bright wisps stretching many arcminutes long. Jeff, my father, and I were ecstatic — we had spotted Halley again (my father for the first time) and it was an impressive sight. Before dawn we observed Halley with the naked eye; it was a bright elongated patch and showed several degrees' worth of tail.

Dawn broke very quickly, and we were only part of the way home when daylight burst on the scene. The whole experience seemed dreamlike. As I began dozing in the backseat of the car, my father said, "Dave, after all these years I can almost appreciate why backyard astronomers do what they do!" Halley, there's hope for you yet. — *David J. Eicher*

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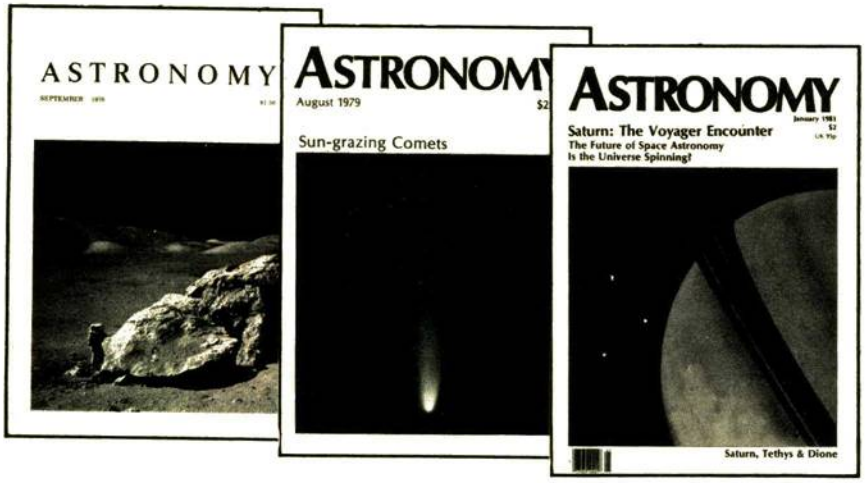

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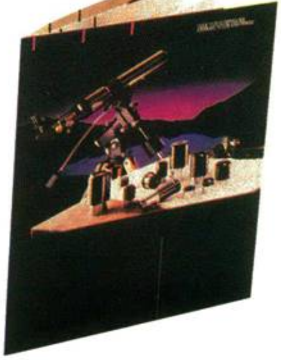

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ASTRONOMY Reviews

Comet
Carl Sagan and Ann Druyan
398 pages, hardcover, $27.50
Random House (1985)

With the recent flood of books on comets, it's difficult to believe that one of them could present a fresh approach. But *Comet*, the product of husband-and-wife team Carl Sagan and Ann Druyan, is a unique work that will prove useful to all comet observers.

Carl Sagan is probably the most well-known astronomer alive today. He has brought a fresh perspective to astronomy for millions of people, particularly through the *Cosmos* television series and book. Ann Druyan served as co-writer of the television series. Like *Cosmos*, *Comet* is written for the layman.

From the first page, *Comet* is obviously different from most books on comets. It is not about Comet Halley, as most books these days are, but about all comets. It is a large-format "coffee table" book with approximately two-thirds of each page devoted to text and the outer margins bedecked with a wide variety of illustrations, quotations, and captions. In the top right-hand corner of each right-hand page is an illustration depicting Halley's position along its orbit during a given year. By flipping the pages, you can create a movie of Halley's motion, a clever idea. The illustrations are plentiful and include many elegant paintings. Visually, the book is striking.

Comet begins by giving the reader a ride on a comet — an interesting perspective. From there, the authors examine the impact of comets on ancient cultures. In most cases, comets were thought of as evil omens.

The discussion then moves to a scientific treatment of comets including an extensive chapter on Edmond Halley. The authors go beyond telling us about Halley's work on comets, which was only a small fraction of his scientific endeavors.

Sagan and Druyan discuss several other early astronomers as well, including some who are rarely mentioned in popular-level books on comets (Immanuel Kant, for example). These details make the book very enjoyable, although it's unfortunate that the authors did not include some of the more recent comet scientists.

The anatomy of comets, their orbital characteristics, and their chemical makeup are discussed in subsequent sections. The authors spend eight pages covering inner coma detail, speculating on the broad use of the swastika as a symbol by ancient cultures. They attribute this to ancient observers seeing jets from a rotating cometary nucleus when it was very close to Earth. They point to a Chinese observation that resembles a swastika as supporting evidence.

Unfortunately, neither Sagan nor Druyan seem to realize that even if a comet is very close to Earth, its jet activity is only very slightly brighter than the surrounding coma and probably would not have sufficient angular extent to be noticed. The Sagans miss the more obvious answer that the Chinese "swastika" comet may simply represent multiple tails of a comet seen head-on.

The second major part of *Comet* deals with the formation and death of comets. This discussion centers on the Oort Cloud, the birthplace of trillions and trillions of comets, and how it relates to the formation of the solar system.

Throughout the book, the authors use comets as springboards to discussions of a wide range of astronomical topics. This is one of the best aspects of the book. The reader comes away with a broader understanding of astronomy, not just comets.

No modern book on comets would be complete without a section on the speculative theory about the extinction of the dinosaurs by cometary impact — the "death star" and all. Sagan and Druyan provide a reasonable account of these theories.

The final section of *Comet* includes a description of the spacecraft missions to Halley along with some speculative material such as an amusing "how-to" on preventing cometary impacts with Earth and mining asteroids and comets.

Although this book has a lot going for it, there are some serious flaws. The biggest is the unforgivable error of portraying Comet Halley's orbit as prograde instead of retrograde in the book's introduction and in the flip-motion movie frame drawings. The standard way of displaying orbits would have Halley moving in the opposite direction!

The authors appear to be confused about the typical size of a cometary coma. On page 126 they equate the coma to the size of Earth. This is much too small. Even an intrinsically faint comet has a coma several times the size of Earth. Elsewhere in the book, the authors correctly state that a comet's coma can be as large as the Sun.

Only a few editorial errors come up in *Comet*. The most significant involves Wright's drawing of the Great Comet of 1680 (page 66), which includes the Earth and four other cometary nuclei for comparison. The caption, however, includes Earth as one of the nuclei.

Overall, this book is fairly complete, but I did find two aspects that are poorly covered. Very little is said about brightness variations, one of the most interesting physical aspects of comets.

More importantly, the authors fail to adequately relate comets to the layman. They treat comets as the realm of the astronomer and fail to mention that they can be viewed by anyone with modest optical equipment.

With these shortcomings in mind, *Comet* is still an excellent book for the general reader, for whom it was written.
Charles S. Morris.

Nemesis: The Death-Star and Other Theories of Mass Extinction
Donald Goldsmith
166 pages, hardcover, $15.95
Walker (1985)

I first heard about Nemesis from Larry

Niven at a convention where anthropologists and science fiction writers had gathered to create imaginary cultures. The environment was certainly right, for never has a concept jumped so quickly from the pages of science fiction into the scientific journals. Imagine this scenario: A stellar or substellar body at the very outskirts of the solar system periodically slings comets into the inner system. A number of these comets strike Earth and extinguish most terrestrial life. The extinctions open new niches for biological experimentation and in the process speed evolution.

That scenario is a very large mouthful indeed and many scientists find it difficult to swallow whole. On the other hand, few scientists today are willing to dismiss *all* parts of the theory.

Nemesis is as much about how science works as it is about death stars; it even ends with a justification of the scientific method. Goldsmith shows how apparently wacky theories arise (Einstein's general and special theories of relativity, for example) and then become accepted by the majority of scientists, thus becoming the "establishment" that other scientists attempt to overthrow with new evidence. In the process, Goldsmith shows us where the Nemesis theory and its broader cousin the "Shiva" theory, which deals with impacts of whatever kind as the cause of mass extinctions, currently fit into this process. He also shows that a theory does not have to be accepted in its entirety to become compelling.

In the late 1970s, an abnormally high concentration of radioactive elements, believed to come from primitive solar system material, was found in a 65-million-year-old layer of clay. Earth is believed to share these elements in about the same abundance as other solar system material, but since the elements are heavy, they sank toward the Earth's core when the planet differentiated long ago. Today they are rarities in the terrestrial crust.

The discovery of concentrations of these elements in the crust was interpreted by discoverers Walter and Luis Alvarez and others to be the fallout from the impact of a small asteroid or, more likely, a comet. Suspiciously, they determined that the impact took place at about the time the dinosaurs became extinct. The Alvarez team then interpreted this coincidence to mean that the impact *caused* the mass extinction.

Evidence that other mass extinctions in the geological record were associated with impacts was soon found. This led some Earth scientists to conclude that *all* mass extinctions were caused by impacts. Yet other scientists have argued that the dinosaurs and other species may not have died out fast enough to link the impact, which nearly everyone now agrees took place, directly to the extinction. Nonetheless, many people find the close coincidence between the extinction and the impact as extremely suggestive to the point where they now take it as a foregone conclusion that an asteroid "did in" the dinosaurs.

However, other parts of the theory meet with substantially less consensus. Some Earth scientists have tried to argue that extinctions have occurred on a regular basis, usually either 26 or 30 million years apart. The seemingly "small" difference between the two periods is considered critical for distinguishing between two separate models.

The first model might be termed the "galactic" model. When the solar system passes through the plane of the Galaxy every 33 million years, material concentrated in the galactic plane perturbs the Oort Cloud of comets around the Sun and slings some of them toward Earth.

The 26-million-year figure, however, favors a different model. A small star or large planet in an extremely elongated orbit around the Sun with an aphelion of 2.6 light-years perturbs the Oort Cloud and generates the infalling comets. Neither model has sufficiently compelling evidence to win over scientists who prefer the original model.

But the 2.6 light-year aphelion, which

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is required to explain an orbit that takes 26 million years, is the Achilles' heel of the Nemesis theory. Many astronomers find it hard to see how an orbit that extends over halfway to the nearest star could remain stable long enough to account for all the known extinctions. On the other hand, with some theoretical arm waving, this instability can also be used to account for variations in the 26-million-year period of the extinction record. Goldsmith suggests the only way to settle the argument is for someone to actually find Nemesis or to prove that it doesn't exist.

It should be clear from all this that there's a lot of speculation going on, in some cases speculation backed up by remarkably little evidence. That an impact killed the dinosaurs now seems probable, but I have even more trouble than Goldsmith does with the Nemesis parts of the theory.

Nemesis is one of the best organized books I've read. Five chapters that cover the four major theories and a summary are subdivided into one- or two-page essays, each of which may be read by itself. Coupled to a relatively complete index, this format makes it unusually easy to look up individual subjects. A few well-chosen black-and-white drawings and photographs illustrate the text.

Nemesis would provide very good supplementary reading for a high school or junior college science course. Aside from covering an interesting subject, it does a good, honest job of explaining how science works. *Donald F. Robertson.*

Astrophotography for the Amateur
Michael A. Covington
168 pages, hardcover, $24.95
Cambridge University Press (1985)

Between the covers of this beautifully produced and illustrated book lies something for almost every astrophotographer. From simple star trail photography to long exposures of deep-sky objects, Covington's book covers it all. Although there is a heavy emphasis on theoretical aspects of photography, the equipment and techniques required to take high-quality astrophotographs are also discussed in detail.

Unfortunately, the wealth of information Covington provides is often like buried treasure: you have to dig to find it. For this reason, the book will be a little difficult for novices like myself who want a step-by-step tutorial on how to make great astrophotographs.

For example, information on how to select a 35mm camera for prime focus lunar photography is spread among Chapters 2, 5, and 8. Moreover, one of the most critical factors for vibration control — a manual mirror lock-up — is described as "desirable" rather than necessary. Interchangeable focusing screens are rated the same way. While these statements may be correct, I believe that most experienced lunar photographers would rate both as mandatory features for sharp, crisp photos.

Another comment that could prove costly to beginners concerns time exposures and shutter control. Covington suggests that automatic shutters are okay if used "preferably without running down the batteries." Even at discount store prices, using an electronic shutter camera for astrophotography can cost between $4 and $8 per time exposure in batteries alone, making mechanical time exposure control a financial if not a technical necessity. Since most of today's popular-priced cameras are completely electronic and do not have mirror lock-up mechanisms or interchangeable focusing screens, a newcomer following Covington's guidelines could easily decide to purchase a camera that is both unsuitable for lunar photography and too expensive (in terms of battery cost) to use for even simple star trails.

Most readers, however, will be beyond the entry-level stage in astrophotography and shouldn't be bothered by problems of this sort, so these are hardly major deficiencies. But for the novice, this lack of "nuts and bolts" information at the most fundamental level can be both misleading and frustrating.

The discussions on film processing are also oriented more toward the seasoned photographer than the novice. For those with darkroom experience, the information provided will prove invaluable. Black-and-white film processing, including recommended chemistries and procedures, is covered in detail, as are slide duplication and printmaking. But for those who must use a commercial lab for processing, more information on how to select a lab and the types of services that are available would have been very helpful.

An area that I'm sure most readers would like to see expanded is the "Do It Yourself" projects section. Both astronomical and photographic equipment can be expensive, so homemade accessories that can make our life a little easier and save us some money are greatly appreciated. Unfortunately, only one project — an electronic drive corrector — is presented. While there is no question that this is something everyone will eventually need, it takes a fair amount of electronic skill to build such a device. Some useful accessories that a reasonably handy "wood butcher," as opposed to an electronics technician, can easily build are missing.

There are the usual problems with a first-edition book on astrophotography: a few poor color separations and a good number of pictures printed backwards, most noticeably the M-42 and M-51 shots and a small wide-field photo of M-8 and M-20.

Although it isn't written at a level suitable for the beginner, Covington's book is excellent. It contains a discussion of practically everything: film specifications and hypersensitizing, exposure tables, developing and printing procedures, focal length and ratio computations, and theoretical and practical limits of performance for various optical configurations. It's all here with convenient tables, excellent illustrations, and beautiful photographic examples.

In the best of all worlds, *The Compleat Astrophotographer* would be a three-volume set. Volume I would be the *Novice's Guide to Astrophotography* and Volume III would be the *Professional Astrophotographer's Handbook*. Volume II, which everyone will need at some point in their efforts, is available today, and Michael Covington has written it. *Gene E. Sengstock.*

The Quest for SS 433
David H. Clark
206 pages, hardcover, $15.95
Viking (1985)

The Quest for SS 433 recounts the discovery of SS 433, a mysterious star-like object in Aquila orginally thought to be a variable star. Clark describes the detective story that ensued as astronomers proposed ideas and conducted research on this strange high-energy celestial object.

Protostars and Planets II
David C. Black and Mildred Shapley Matthews, eds.
1293 pages, hardcover, $45
University of Arizona (1985)

A massive tome containing forty-four papers by some sixty-seven different authors on all facets of the evolution and behavior of gas clouds, protostars, and solar systems in the Galaxy.

Superforce
Paul Davies
255 pages, hardcover, $16.95
Simon and Schuster (1984)

A glance at the table of contents of Paul Davies' book on the search for a Grand Unified Theory of nature promises an exciting tour of contemporary theoretical physics. And indeed, the reader is not disappointed as the author presents a comprehensive and interesting account of physicists' attempts to develop a single theory that describes the nature and origin of all known forces and particles in the universe.

Focusing on the value of mathematics and the use of symmetry and "beauty" as a guide to truth, Davies describes in an entertaining narrative the recent progress that has been made in understanding the

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nature of the four known physical forces and the world of subatomic particles. The unification of the electromagnetic and weak forces comes as a result of the symmetries of quantum electrodynamics. A similar approach leads to the assimilation of the strong force into the consortium by quantum chromodynamics. This sets the stage for the development of a "superforce" theory, which unifies all forces (including gravity) into one consistent formulation.

The chapters that follow discuss the unique problems of this endeavor and present some of the avenues currently being pursued. Davies explains the relationship between the investigations into the superforce and the Big Bang theories for the origin of the universe and shows how these studies can help us understand the creation and subsequent evolution of the cosmos.

Up until Chapter 2 the book provides a satisfying, if not rigorous, scientific account of the history and latest developments of the physical theories of forces and particles. I have two mild criticisms to make of the following chapters, which form the bulk of the work.

First is the style, which will strike readers as rather sensationalistic. This is best exemplified by a passage that suggests we could become "Lords of the Universe" by controlling the superforce. This would enable us to "manipulate the dimensionality of space itself, creating bizarre artificial worlds with unimaginable properties" — an astonishing statement, given that Davies has already admitted we have no realistic expectation of even experimenting with the superforce, much less controlling it!

The second criticism concerns the book's weak organization, which makes the direction of the narrative difficult to follow. The opening chapter has the ring of a prologue that never seems to end as chapter succeeds chapter. Davies provides no hint as to where his discussion will lead nor does he ever review the ground previously covered. It has to be said, however, that despite these weaknesses, the reader is left with a sound basic understanding of the general features of the theories and issues involved.

The final two chapters are a disappointing conclusion to an otherwise informative and entertaining book. The reader is not prepared for the philosophical excursions into "cosmic unity" and the "meaning behind existence," both of which have little foundation in the mathematical and physical concepts presented earlier. The first of these discussions, though deeply rooted in scientific thought in terms of Mach's Principle, is presented on the same footing as the more concrete theories covered in the book; this tends to blur the distinction between observable phenomena and logical constructions.

The "meaning" discussion uses arguments based on the beauty and simplicity of the laws of nature. It concludes that the universe was purposefully designed for the benefit of mankind. Davies' failure to warn readers about the speculative nature of these concluding discussions has the unintended effect of making the reader wonder how much he can trust other parts of the book.

Shortcomings aside, *Superforce* is a credible attempt to present a difficult topic in an understandable and entertaining manner. Although a good overall organization is lacking, individual concepts are treated with clarity. The reader leaves the book with a better appreciation for the modern scientist's perspective on the physical universe. *David Jourdan.*

Astronomy and Astrophysics Abstracts, vol. 38

S. Boehme, *et al.*, eds.
919 pages, hardcover, $68.50
Springer-Verlag (1985)

This volume in a series which appears twice a year covers the astronomical literature for the latter part of 1984. It gives a detailed, classified listing for 9,361 astronomy articles, papers, books, and anthologies. In most cases, it provides a summary of the article or paper mentioned — even for papers that appeared in conference proceedings. The last 200 pages contain author, key word, and subject indexes.

Space Disc 5 — ASTRONOMY

12-inch laser video disk, no price given
Video Vision Associates (1985)

One of the great recent advances in storing and presenting information has been the video disk. Literally thousands of individual frames can be stored and accessed almost instantly from a single disk, making the disks ideal for teaching and reference.

Space Disc 5 is a two-sided high-quality laser video disk that contains a tremendous amount of data on all types of astronomy. This includes diagrams of stellar spectra, explanations of parallax, non-optical astronomy (ultraviolet, infrared, and x-ray), relative sizes of planets, and so forth. It is a photovisual history of modern astronomy: a complete Messier catalogue (photographed and reproduced in different wavelengths), a gallery of detailed shots of planets taken by the Mariner, Voyager, and Venera probes — the list goes on and on.

The last part of each side contains a movie. These include Space Shuttle film clips and computer simulations of neutron star collapses, galaxy formation, the apparent parallax change of familiar constellations during a hypothetical trip to Aldeberan . . . and anything else the compilers could get their hands on!

Except for some of the motion picture segments, the disk has no sound track, which is no detriment since the disk is obviously designed for educators, astronomy departments, and large high school libraries.

The authors call *Space Disc 5* "a collaborative effort of the first order," and I agree completely. The amount of intellectual and visual material stored here is staggering. This disk (which is part of a series) is a must for anyone who teaches astronomy or is a serious amateur and/or videophile. I most wholeheartedly recommend it. *Bryan P. Shumaker.*

Comet Predictions for 1987

C. Townsend, J. Rogers, and S. Hanssen
58 pages, looseleaf; $6 U.S.A., $8 abroad
Published by the authors (1986)
[Order from: C. Townsend, 3521 San Juan Ave., Oxnard, CA 93033]

This publication provides coordinates, magnitudes, distances, and accessibility data for twenty-four periodic comets that will be observable during 1987. The predictions were derived from numerical integration of reliable starting orbits using a home microcomputer. Planetary perturbations and nongravitational effects are taken into account.

Stability of the Solar System and Its Minor Natural and Artificial Bodies

Victor G. Szebehely, ed.
424 pages, hardcover, $54
Reidel (1985)

The proceedings from a NATO science conference held in Cortina d'Ampezzo, Italy, in 1984. This is a highly technical volume detailing orbital and mechanical behavior of various solar system bodies.

The Extraterrestrial Encyclopedia

Joseph A. Angelo, Jr.
254 pages, hardcover, $24.95
Facts on File (1985)

The Extraterrestrial Encyclopedia is a compilation of terms and concepts pertinent to the search for life elsewhere in the universe. The book holds over 500 entries, ranging from abiotic to Zoo hypothesis, and 150 photographs.

The Universe

Heather Couper and David Pelham
12 pages, hardcover, $19.95
Random House (1985)

This is a "pop-up" book showing six scenes from the history of the universe: the Big Bang, formation of galaxies, star birth, beginning of the solar system, star death, and the possible fate of the universe.

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#128 2.4" Equatorial	35X, 50X, 72X, 100X, 129X	7°12′	60 mm, f/15	6X—2 mm, 6°22′ field	34½ in.	60 in.	24 lb.
#140 3" Altazimuth	48X, 67X, 96X, 131X, 171X	4°20′	75 mm, f/16	8X—30 mm, 4°22′ field	47 in.	59 in.	23 lb.
#142 3" Equatorial	48X, 67X, 96X, 131X, 200X	4°20′	75 mm, f/16	8X—30 mm, 4°22′ field	47 in.	59 in.	46 lb.
#131-C 3" Compact Equatorial	48X, 67X, 96X, 131X, 171X, 200X	4°20′	75 mm, f/16	8X—30 mm, 4°22′ field	19 in.	60 in.	32 lb.
#150 4" Altazimuth	60X, 83X, 120X, 167X, 214X, 250X	3°22′	100 mm, f/15	10X—40 mm, 2°54′ field	63 in.	64 in.	50 lb.
#152 4" Equatorial	38X, 60X, 83X, 120X, 167X, 214X, 250X	3°2′	100 mm, f/15	10X—40 mm, 2°54′ field	63 in.	66 in.	100 lb.

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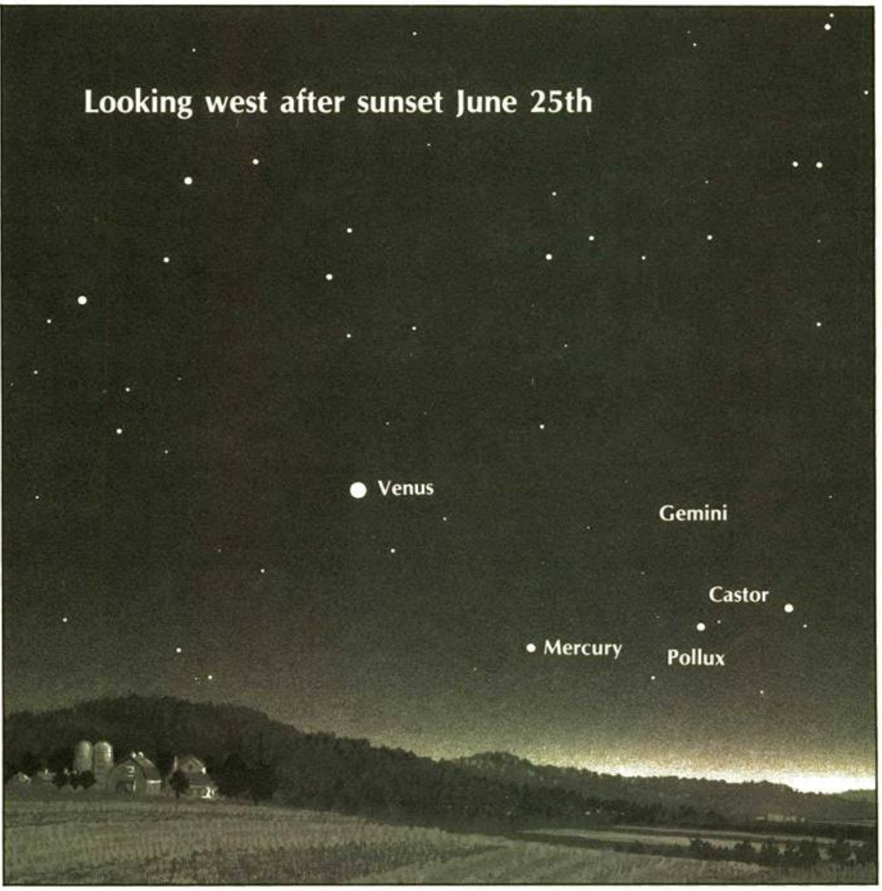
Eye on the Sky

Mercury Joins Venus in the Evening Sky

by Robert Burnham



The Wanderers

When the Sun finally sets late in the warm buggy evenings of June, two planets lie in the western sky. One of them is bright and easy to identify, the other somewhat fainter and more difficult. Start your planet search at a nearby park or schoolyard that has a clear, unobstructed horizon to the west and northwest.

The bright object you see over the trees in the west is **Venus**, which reaches its greatest visibility in the evening sky this month. Venus shines at magnitude −4.0, making it brighter than anything but the Sun and Moon. (Compare Venus with the Moon on the 10th when the Moon passes nearby.)

Venus' motion is taking it on an eastward path along the zodiac through a backdrop of stars belonging to Gemini and Cancer. You won't get a clear view of these winter and spring constellations, however, because they are too near the horizon and the remaining twilight largely washes them out.

To find this month's other "evening star," **Mercury**, use Venus as a guide. After the first week of June, Mercury has roughly half the elevation of Venus and lies some 10° — the width of a fist at arm's length — to the right. (During the first week of June, Mercury is too low to see easily.) Many times dimmer than Venus, Mercury's brightness ranges from −0.7 magnitude on June 7 to +0.8 on June 30. You may find that wide-field binoculars help you to locate the planet.

Mercury reaches its highest elevation on June 17 but will be at least 8° high from the 10th through the 26th (45 minutes after sunset). On June 25, Mercury reaches its greatest angular separation from the Sun; that evening it also makes a pretty grouping with Venus and two bright stars, Castor and Pollux, in Gemini.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

After spotting Venus and Mercury, turn to face southeast. Over the trees and buildings you'll see **Saturn** gleaming pale yellow. Saturn is in the constellation of Scorpius and lies near its brightest star, Antares. You can tell Saturn from Antares because Saturn is about twice as bright, not so ruddy, and lies higher in the sky. Saturn shines at 0.1 magnitude, Antares at 0.9.

The next planet visible to the naked eye — the Red Planet **Mars** — rises in the southeast about an hour later just as Venus is setting. Mars lies in the crowded Milky Way starfields of Sagittarius, where it glows as an amber-orange beacon at magnitude −1.9. Mars is approaching opposition to the Sun (July 10), when it will be at its brightest (magnitude −2.6) for the next two years. Can you detect a steady increase in its light during June?

The fifth and last of the sky's naked-eye planets is **Jupiter**, which rises two hours behind Mars. Jupiter inhabits Aquarius, a dim constellation, and shines brilliant white at magnitude −2.4. There's no mistaking it. If you miss Jupiter when it rises about 1 or 2 a.m., you can catch it in the south-southeast before morning twilight brightens the sky. Jupiter will be about 35° to 40° above the horizon.

One last "planetary" event concerns our own **Earth**. On June 21 at 12:30 p.m. EDT, the Sun will reach its greatest distance north on the celestial sphere. This moment marks the solstice and the beginning of summer for the Northern Hemisphere.

June signals the return of warm weather to much of the Northern Hemisphere, bringing opportunities for camping under the stars. This shot shows Cassiopeia's star trails lying high above an observing camp. Photo by Michael J. Himmes.

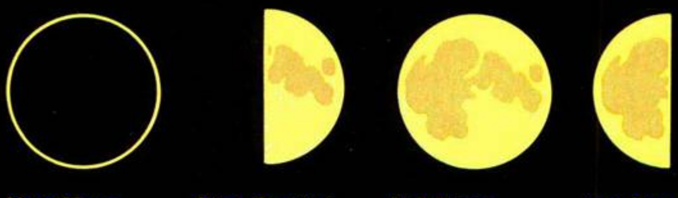
The Starry Sky

June nights are the year's shortest, with the sky not becoming fully dark until quite late. When twilight finally fades into night, the spring constellations in the south and west are being chased offstage by the rising stars of summer in the east.

Let's begin with the familiar Big Dipper, which is made up of the brightest stars of **Ursa Major** the Great Bear. The Dipper lies to the upper left of Polaris, the pole star, when you face north. Its curved handle leads your eye naturally to two other stars, each the brightest in its constellation.

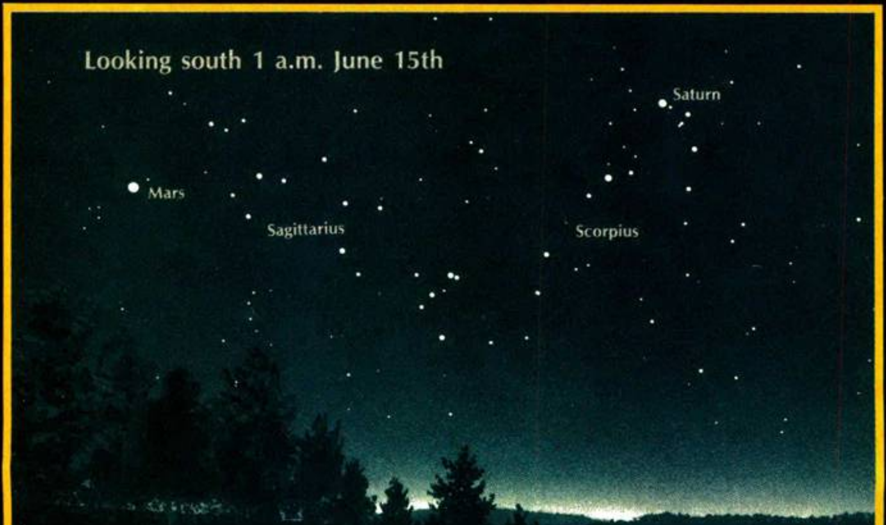
The first bright star found by extending the handle's arc is honey-colored Arcturus, which belongs to Bootes the

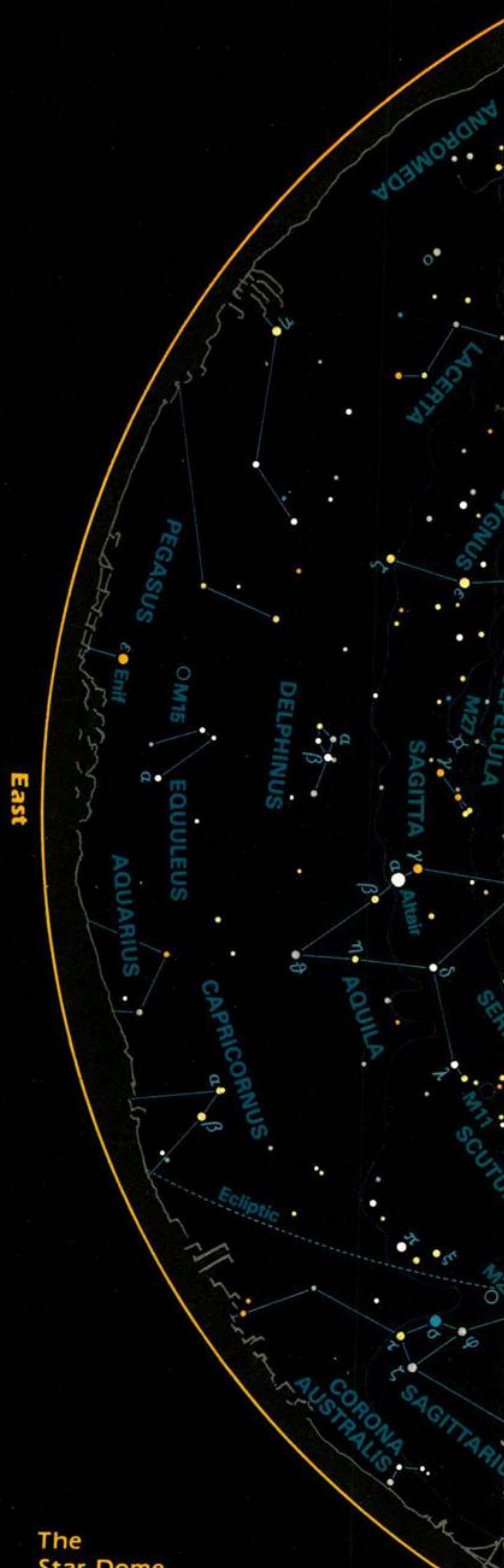
June Night Sky



New Moon	First Quarter	Full Moon	Last Quarter
June 7	June 15	June 21	June 28
10:00 a.m. EDT	8:00 a.m. EDT	11:42 p.m. EDT	8:53 p.m. EDT

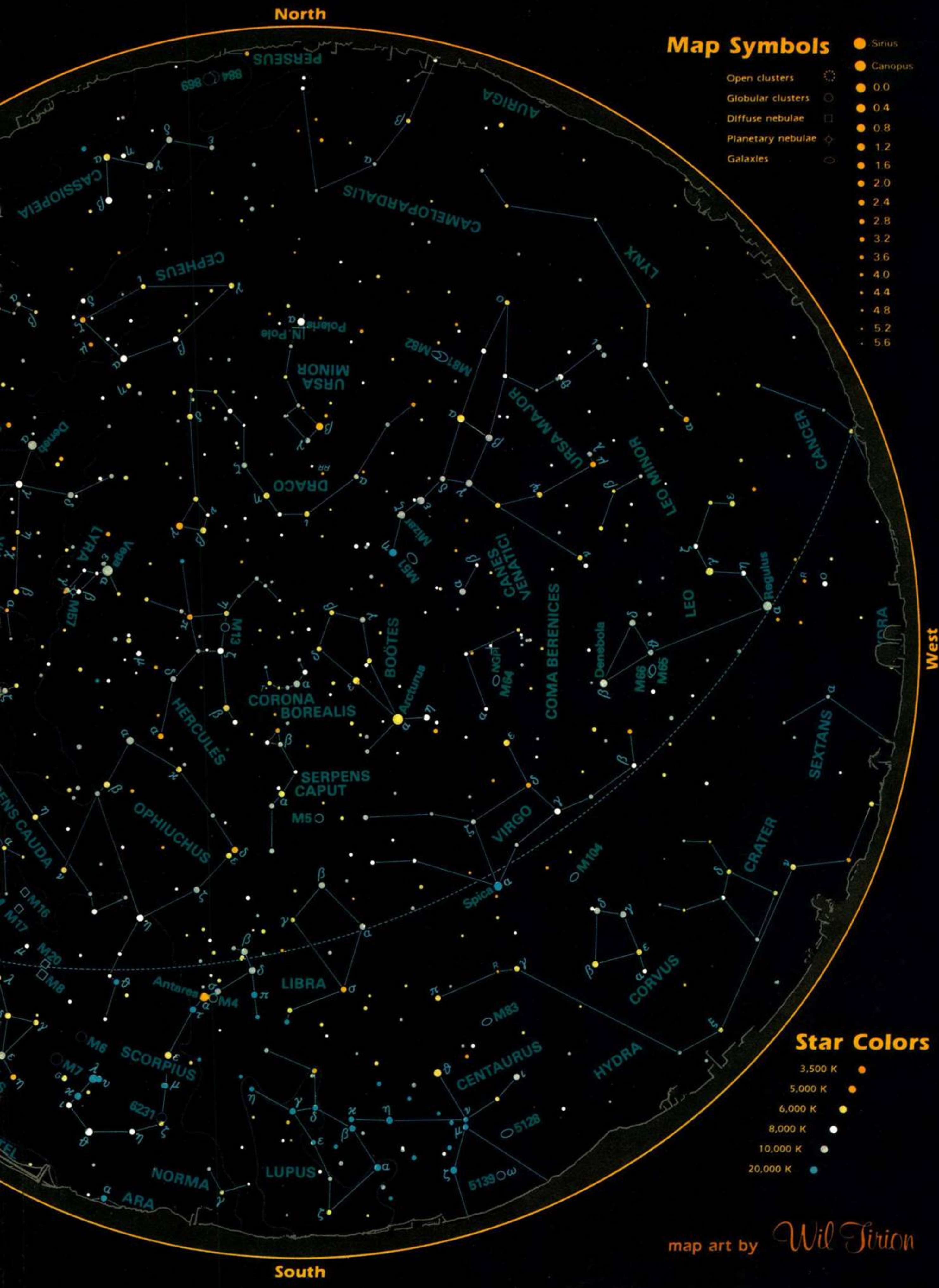
6th	The Moon is farthest from Earth at 9:55 p.m. EDT: 252,626 miles.
7th	New Moon occurs at 10 a.m. EDT.
9th	The Moon lies north of Mercury in the evening sky.
10th	Beginning tonight and continuing through the 26th, Mercury will be at least 8° high in the evening sky 45 minutes after sunset. This is one of the best apparitions for Mercury this year. The Moon, Venus, and the stars Castor and Pollux will group together in the western sky after sunset.
11th	Uranus is at opposition to the Sun.
14th	The summer Milky Way will be at its highest in the sky around 2 a.m. local daylight time.
15th	First Quarter Moon is at 8 a.m. EDT.
21st	The Moon is closest to Earth at 8:49 a.m. EDT: 222,244 miles. The solstice occurs at 12:30 p.m. EDT: summer begins. Full Moon is at 11:42 p.m. EDT.
25th	Mercury is at greatest eastern elongation from the Sun in the evening sky (25°). It will be visible low in the west-northwest each evening until early July. Mercury joins Venus, Castor, and Pollux in the sunset sky.
26th	Neptune is at opposition to the Sun.
27th	The Moon lies about 2° south of Jupiter in the predawn sky.
28th	Last Quarter Moon is at 8:53 p.m. EDT.


Looking south 1 a.m. June 15th
Saturn
Mars
Sagittarius
Scorpius


ANDROMEDA
LACERTA
CYGNUS
PEGASUS
Enif
M15
DELPHINUS
EQUULEUS
AQUARIUS
M27
ECULA
SAGITTA
Altair
AQUILA
CAPRICORNUS
M11
SCUTU
Ecliptic
CORONA AUSTRALIS
SAGITTARI
East

The
Star Dome
shows how the
sky looks at:

Midnight on June 1
11:00 p.m. on June 15
10:00 p.m. on June 30


North
Map Symbols
Open clusters
Globular clusters
Diffuse nebulae
Planetary nebulae
Galaxies
Sirius
Canopus
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
PERSEUS
884
869
AURIGA
CASSIOPEIA
CAMELOPARDALIS
LYNX
CEPHEUS
Polaris
N. Pole
M81
M82
URSA MINOR
URSA MAJOR
LEO MINOR
CANCER
Deneb
DRACO
Mizar
M51
CANES VENATICI
LYRA
Vega
M57
M13
BOÖTES
COMA BERENICES
Denebola
LEO
Regulus
M66
M65
NGP
M64
HYDRA
West
CORONA BOREALIS
Arcturus
HERCULES
SERPENS CAPUT
M5
SEXTANS
OPHIUCHUS
VIRGO
SERPENS CAUDA
M104
CRATER
Spica
M16
M17
M20
M8
LIBRA
CORVUS
Antares
M4
M83
M6
M7
SCORPIUS
CENTAURUS
HYDRA
6231
5128
NORMA
LUPUS
5139
ARA
South
Star Colors
3,500 K
5,000 K
6,000 K
8,000 K
10,000 K
20,000 K

map art by Wil Tirion

Top: The great Milky Way star clouds of Sagittarius, the summer sky's grandest feature, are shown in this 10-minute star trail photo by Nelson Chow. Bottom: A guided photograph of the Sagittarius region reveals far more detail in the tiny clusters and nebulae inhabiting this part of the sky. The bright "star" near M-8 is Jupiter. Photo by A.R. Drake.

Herdsman, an ancient constellation whose origins are long lost in time (see Skylore). Just to the east of Bootes lies a lovely little crescent of stars called **Corona Borealis** the Northern Crown. The Greeks knew this constellation as "the wreath," another appropriate name. Its brightest star is called Alphecca.

Continuing the arc southwest from Arcturus, we meet bright white Spica in **Virgo** the Virgin. Some myths identify Virgo with Ceres, the goddess of grain; Spica then becomes an ear of wheat held in her hand. Between Spica and Arcturus and the western horizon lies another large zodiacal constellation, **Leo** the Lion. Dimmed now by its low elevation, Leo will soon slip out of view. Its brightest star is Regulus.

If you trace a line from Regulus through Spica and extend it about the same distance southeast, you encounter Antares, the eye of **Scorpius** the Scorpion. (Don't confuse Antares with its temporary "guest," the planet Saturn; Antares is redder, dimmer, and lower.) Antares means "rival of Ares [Mars]," which it resembles in color and brightness.

West of Antares, three stars form a short vertical line. These are the Scorpion's claws that eternally grasp for **Libra** the Balance. Libra is a faint, diamond-shaped zodiacal group that lies between Scorpius and Virgo. The rest of the Scorpion curves east and south from Antares in a chain of 2nd- and 3rd-magnitude stars that resembles a hook. The Scorpion ends at Shaula, the "stinger-star," in the insect's tail.

North of Antares looms the large, dim figure of the Serpent-Bearer **Ophiuchus**. Its brightest star is called Rasalhague, Arabic for "head of the serpent-charmer." Bell-shaped Ophiuchus was thought to be grasping Serpens, who is depicted in two halves. The head of Serpens (**Serpens Caput**) wriggles between Ophiuchus and Arcturus while his tail (**Serpens Cauda**) thrashes the Milky Way.

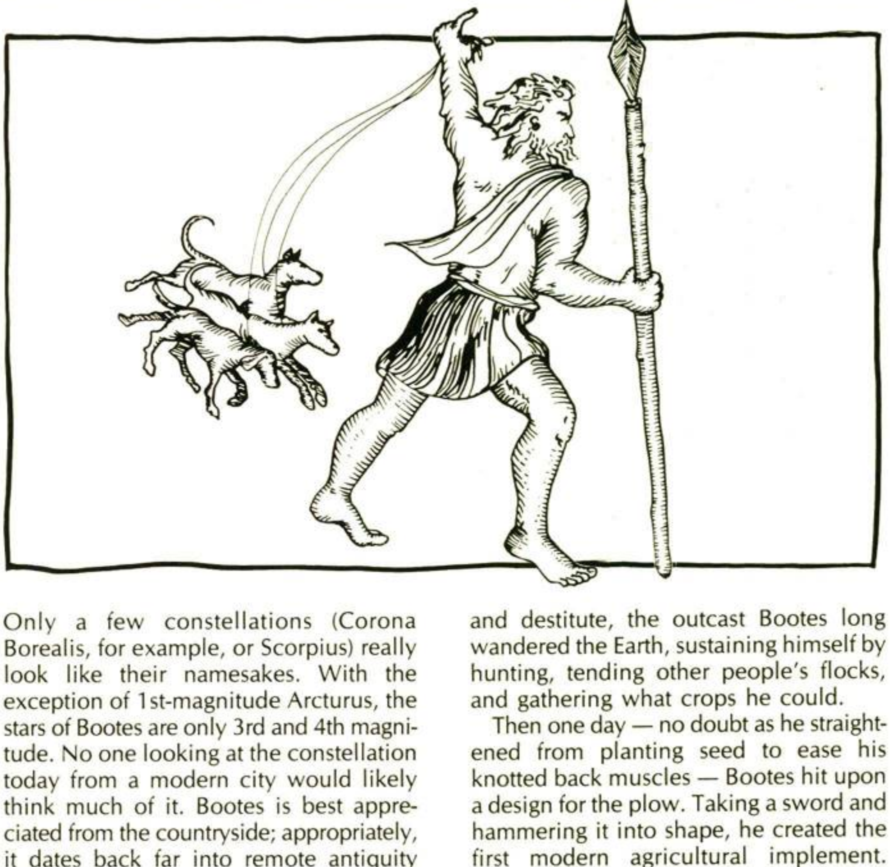
Directly north of Ophiuchus is the relatively faint figure of **Hercules**, a somewhat unimpressive collection of stars for such a famous figure. The easiest part of Hercules to spot is the "keystone" of four 3rd-magnitude stars. On a clear night, look either with the naked eye or binoculars for the globular cluster M-13 on the keystone's western edge.

Below Hercules when you face east is a brilliant white star. This is Vega, the luminary of **Lyra** the Lyre. In ancient legend, Lyra was the melodious instrument given by its inventor Hermes to Apollo, who passed it on to his son Orpheus. Lyra is one of the smallest constellations, but few are more distinct. Later in the summer and early autumn, the evening hours will show Vega passing directly overhead.

Rising over the trees below Lyra is the **Milky Way**. From a dark-sky site it will be clearly visible and breathtaking, yet from typical suburban locations horizon haze will dim it significantly. No matter — July and August will display all its glories at their peak.

Skylore

Anyone who tries to explain the constellations to a non-astronomical friend usually encounters the rather exasperated reaction: "Whoever thought up these names sure had a good imagination!" Only a few constellations (Corona Borealis, for example, or Scorpius) really look like their namesakes. With the exception of 1st-magnitude Arcturus, the stars of Bootes are only 3rd and 4th magnitude. No one looking at the constellation today from a modern city would likely think much of it. Bootes is best appreciated from the countryside; appropriately, it dates back far into remote antiquity when all of mankind lived a rural, unlight-polluted existence.



Bootes has been variously called a Herdsman, a Plowman, a Bear-Driver, and a Wagoner. He is mentioned in *The Odyssey* as a wagon driver but was also called Arctophylax ("bear-keeper") by Hesiod in the 8th century B.C. Arcturus, Bootes' brightest star, means "bear-guardian" in Greek and may originally have stood for the entire constellation (see Eye on the Sky, June 1981). As the stars wheel westward around the pole, it's easy to envision Bootes perpetually chasing the Great Bear of Ursa Major.

Bootes is most often depicted as a man standing erect or running with a spear in his right (eastern) hand, the spear being a token of his guardianship. In some versions, however, his left hand holds the leashes of two dogs, Asterion and Chara, though it wasn't until 1690 that Johannes Hevelius created the adjoining constellation Canes Venatici, the Hunting Dogs, to represent them.

In one famous myth, Bootes (under the name Icarius) was the unfortunate who, having learned from Dionysus how to make wine from grapes, was promptly murdered by his friends when they awoke with hangovers (see Eye on the Sky, February 1986).

But considering his stellar neighbors, the most apt legend to explain Bootes is the one in which he is the brother of Erectheus, an Athenian leader. Erectheus was a scoundrel who selfishly robbed Bootes of his inheritance and turned him out onto the street, penniless. Dejected and destitute, the outcast Bootes long wandered the Earth, sustaining himself by hunting, tending other people's flocks, and gathering what crops he could.

Then one day — no doubt as he straightened from planting seed to ease his knotted back muscles — Bootes hit upon a design for the plow. Taking a sword and hammering it into shape, he created the first modern agricultural implement. Hitched to the yoke of oxen, the new invention simplified the work of planting and increased the harvest yield tremendously. Delighted with his great discovery, Ceres, the goddess of grain and plenty, beseeched Zeus to honor Bootes by placing him in the sky.

And so it is that as he rises in late spring and early summer, Bootes has near him his famed plow (the stars of the bowl of the Big Dipper), his oxen (the last two stars in the Dipper's handle), and Ceres herself in the form of Virgo, who is equipped with her emblem, the blazing bright ear of wheat called Spica.

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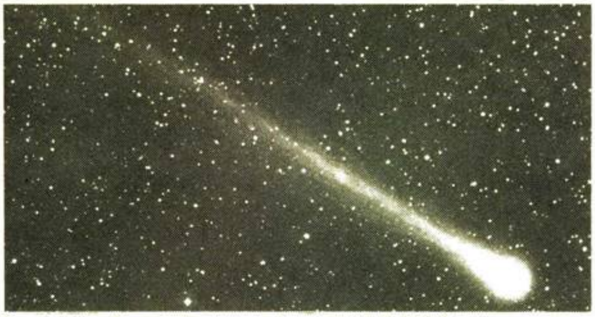
ASTROPHOTO OF THE MONTH



Comet Halley. Photo by David Healy, Jan. 6, 1986. 8" f/1.5 Schmidt camera, gas-hypersensitized (by LUMICON) Tech Pan 2415 film, 5 min. exposure.

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7mm Nagler, 1¼" eyepiece, 82° field	**$175**
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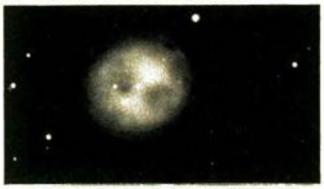

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DEEP-SKY ASTROPHOTOGRAPHY

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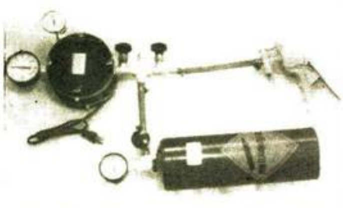

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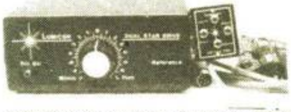

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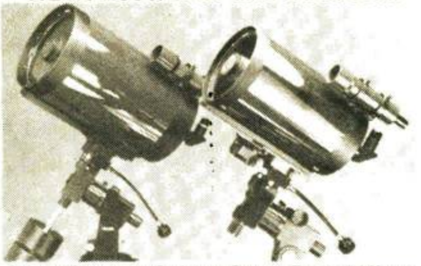
NEW! 2080/GEM and 2120/GEM



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The Meade 2080/GEM and 2120/GEM telescopes include the same diffraction limited optics as the 2080/2120/LX3. Large, stable German equatorial mount with setting circles, slow motion controls on both axes, large 8X50mm finderscope, 25mm 1¼" eyepiece, integrated polar alignment scope, and heavy duty adjustable height tripod (hardwood for 2080, metal for 2120). The computer control provides automatic object location from an extensive software library of deep-sky objects.

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See Meade 2080/LX3 options	
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Adapter for viewing w/1¼" eyepiece	**$20**
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8'' f/6 NEWTONIAN.........$995

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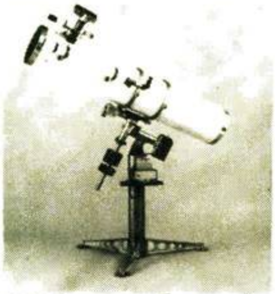

Model 826, 8'' f/6 Telescope w/accessories

Model 628, 6" f/8 with motor drive ($1220 list)	**$785**
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16'' f/4.5 NEWTONIAN......$1995

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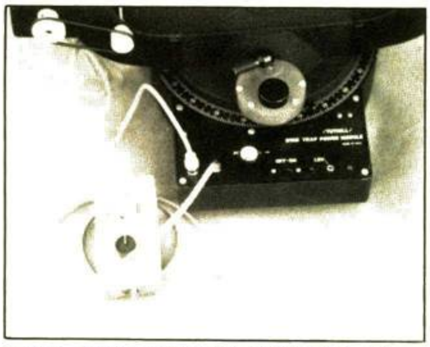

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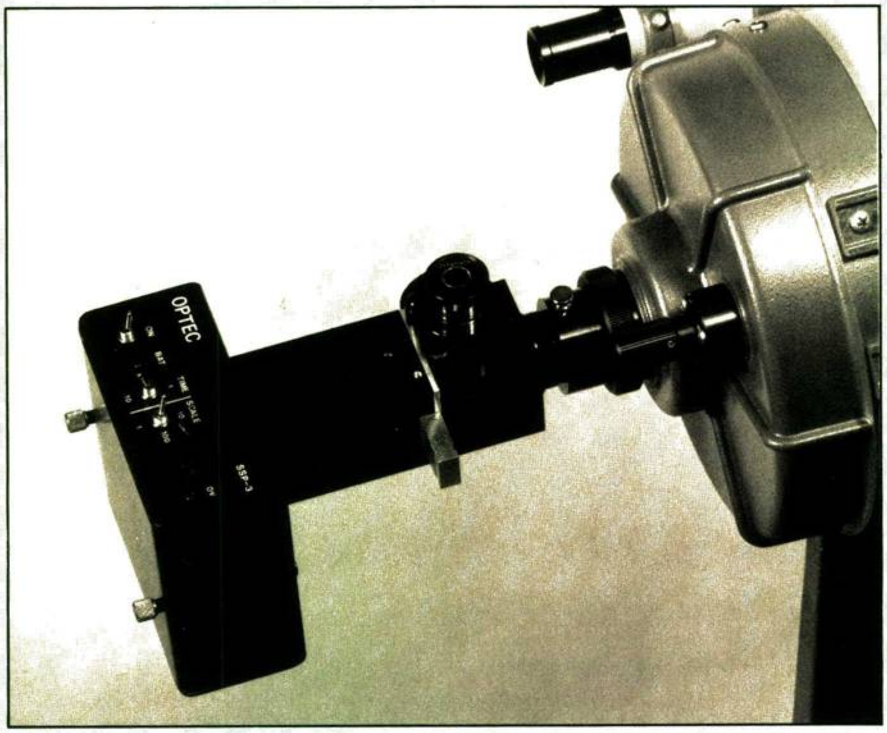
Getting Started In Photoelectric Photometry

by
Frank J. Melillo



Inexpensive photoelectric photometers allow backyard astronomers to make observations with an accuracy once restricted to professionals. Attached to the back of a telescope in its operating position, the photometer measures the intensity of light and displays the result digitally.

You've owned a telescope for several years now and it has rewarded you with countless nights of pleasure. For quite a while you restricted yourself to visual observations, but after seeing the impressive results obtained with a camera and telescope you were lured into astrophotography. Now you find yourself at another crossroad: you still enjoy observing and photographing the heavens, but you wonder what else you might use your telescope for.

Photoelectric photometry might be the answer. For less money than you probably spent on your telescope, you can make observations that are not only personally rewarding but also of scientific value.

Photometry is the measurement of light intensity. It has been around, in one form or another, for a couple of thousand years. The Greek astronomer Hipparchus placed all the naked-eye stars into one of six different brightness classes. His work, later extended by Ptolemy, laid the foundation for our present magnitude system. Based entirely on the human eye as the light detector, the method has its drawbacks.

First and foremost is the nonlinear response of the eye. Evolution has left us an eye that mutes differences in brightness, allowing us to move from an unlit room into bright sunlight without severe consequences. On the down side, this aspect of sight makes us unreliable at discriminating between small brightness differences. Experienced observers, when making magnitude comparisons to nearby stars, can typically estimate the brightness of a given star to within 0.1 to 0.2 magnitudes. While this accuracy is sufficient for certain studies of large-amplitude variable stars, it isn't good enough for most other areas of research.

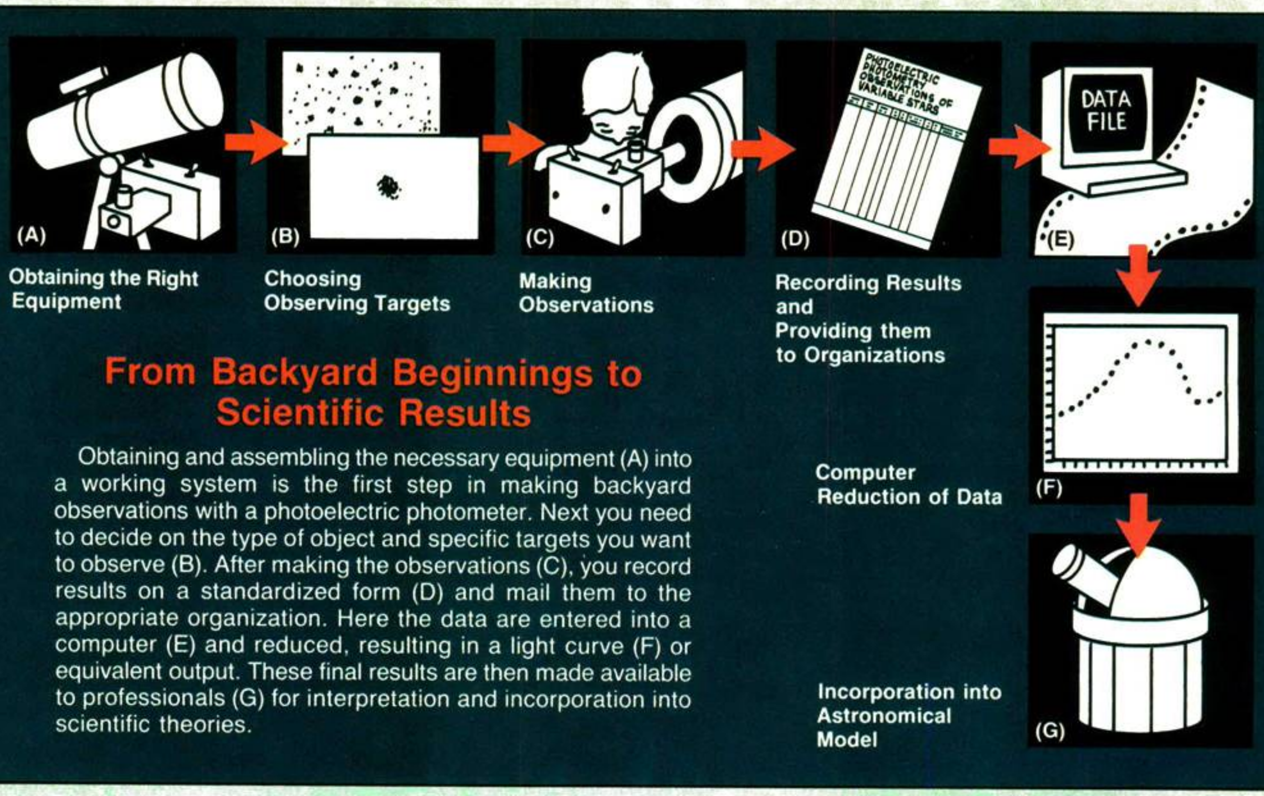
In addition to the limited accuracy of the eye, other factors limit the effectiveness of visual photometry. While the differences in eyesight between people is not a problem (since judgments are made relative to comparison stars), the difference in color sensitivity among individuals is. Because stars come in a variety of colors, any variation in color sensitivity will result in a perceived difference in brightness.

The final problem with visual photometry is the difficulty in extending measurements to fainter stars. Even after the invention of the telescope, such determinations were neither easy nor particularly accurate.

Photography was applied to photometric studies in the 1850s. It had a rapid impact and served to greatly improve both the quality and quantity of photometric data. The brightness of a star seemed to be directly proportional to the size and density of its image on a photographic plate, allowing for easy measurement. Additional advantages included the ability to record thousands of images on one plate and having a permanent record of the observation.

The photographic method led to increased accuracy in the measurement of magnitudes, with errors on the order of 0.02 magnitudes. The new method also required the establishment of a system of standard stars. These stars were selected to cover a wide range of brightnesses and locations, allowing astronomers sufficient choices for comparison purposes.

Despite the enormous benefit of this new technology, it was not without difficulties. The first problem came with the realization that most of the magnitudes determined from photographic plates were different from those determined


(A)
Obtaining the Right Equipment
(B)
Choosing Observing Targets
(C)
Making Observations
PHOTOELECTRIC PHOTOMETRY OBSERVATIONS OF VARIABLE STARS
(D)
Recording Results and Providing them to Organizations
DATA FILE
(E)
Computer Reduction of Data
(F)
Incorporation into Astronomical Model
(G)

From Backyard Beginnings to Scientific Results

Obtaining and assembling the necessary equipment (A) into a working system is the first step in making backyard observations with a photoelectric photometer. Next you need to decide on the type of object and specific targets you want to observe (B). After making the observations (C), you record results on a standardized form (D) and mail them to the appropriate organization. Here the data are entered into a computer (E) and reduced, resulting in a light curve (F) or equivalent output. These final results are then made available to professionals (G) for interpretation and incorporation into scientific theories.

visually. Since the standard photographic emulsion is most sensitive at the blue end of the spectrum and the human eye is most sensitive in the yellow region, hot, blue stars appear brighter photographically while cooler, red ones appear dimmer. (This difference can be mitigated, though not eliminated, through the use of an appropriate filter.)

The most significant problem concerned the nonlinearity of the photographic plate. The relationship between image size and brightness turns out to be quite complex, depending on the batch of plates being used and on the conditions under which the plate is exposed. Photographic photometry is still in use today, though it is no longer the mainstay it once was.

Photoelectric Photometry

Photoelectric photometry has been around since the late 1800s. It was only in the 1930s, however, that the technique became widely available to astronomers and only in the last decade or two that technology has advanced and prices declined to a level where the serious amateur can get involved.

The biggest advantage of the photoelectric method is the linearity of the response — if you observe an object 100 times brighter than another, the response of the system will be 100 times greater. A further advantage is increased accuracy: errors are now in the range of 0.005 to 0.01 magnitudes, even with backyard telescopes.

No doubt you're still a little skeptical. Every good observer has this trait and, frankly, you probably aren't convinced that there is any real reason to get involved in this field. Maybe it is the best way to measure brightness and maybe it can be done in your own backyard, but what good does it do to know how bright an object is?

Quite a lot, actually. Professional astronomers would not have spent the past 50 years pursuing photoelectric photometry if it wasn't giving them important information. And now many amateur observers are supplying data that professionals need for their research on stars, variable stars, asteroids, and other celestial subjects. After getting established in this field, many go on to collaborate with professional astronomers and even coauthor papers in astronomical journals.

Professional astronomers have neither the equipment nor the numbers to make all the observations they want. A professional with access to a large telescope can not spend his observing time doing photometry of bright objects. He knows that the telescope was designed for the study of faint objects and would therefore be unproductive to use when a small one could do the job just as well.

The number situation is even worse. There are currently over 28,000 catalogued variable stars alone, with another 14,000 suspected. With less than 3,000 professional astronomers in the United States, most of them with research interests that lie elsewhere, only a tiny fraction of all variables can be observed at any time.

Professional-Quality Results

Bearing these points in mind, it should come as no surprise that there are advantages to amateur observers doing this kind of work. Included among these are:

- a greater number of observers are available to monitor interesting objects;
- greater flexibility resulting from the availability of a personal telescope;
- more time to make long-term studies of selected objects;
- small telescopes are better suited to the study of brighter objects.

A final point to consider: with currently available equipment, careful amateurs can now make measurements with an error of only 0.01 magnitude. The combination of accuracy and the advantages listed above demonstrates that amateur astronomers can play a significant role in scientific research that might not otherwise be carried forth.

What types of objects would you observe if you become involved in this field? The most frequently cited example, and the one where amateurs have done the most work, is in variable star observing. With the large number of variables and the limited resources of professional astronomers, there are literally thousands of variables that need to be studied, several hundred of which are available to amateur instruments.

Necessary Equipment

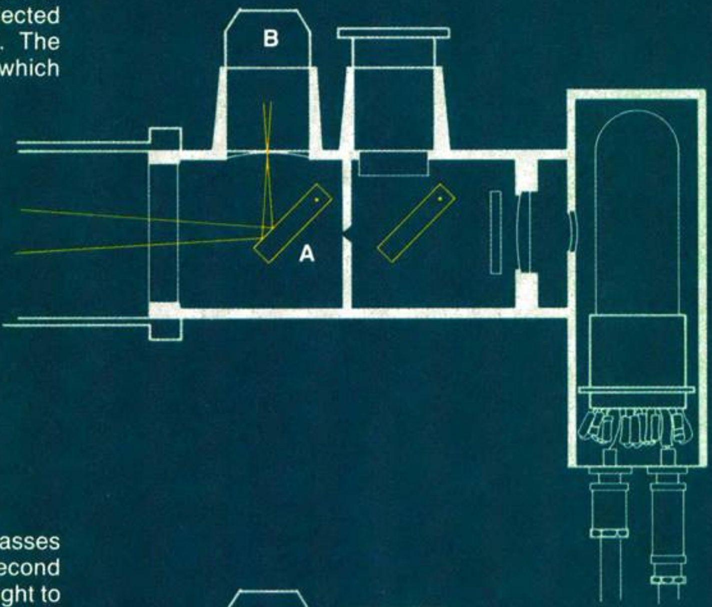
So far we have discussed what photometry is, its role in astronomy, and how easy it is for amateur observers to do. But what kind of equipment is needed to make photometric observations? As it turns out, some of the requirements necessary for astrophotography are also applicable to photometry.

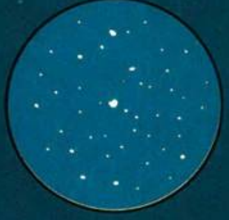
The mechanical demands on your telescope system are more severe than the optical: you have to be able to accurately track the object under study. Normally your clock drive will be called upon to keep a source centered in a small opening (often less than one arcminute in diameter)

The Workings of a Typical Photometer

Finding the Object

Light collected by the telescope is passed to the photometer where it strikes a flip mirror (A) and is reflected to the previewing eyepiece (B). The result is a view of your starfield, which you use to center your target.

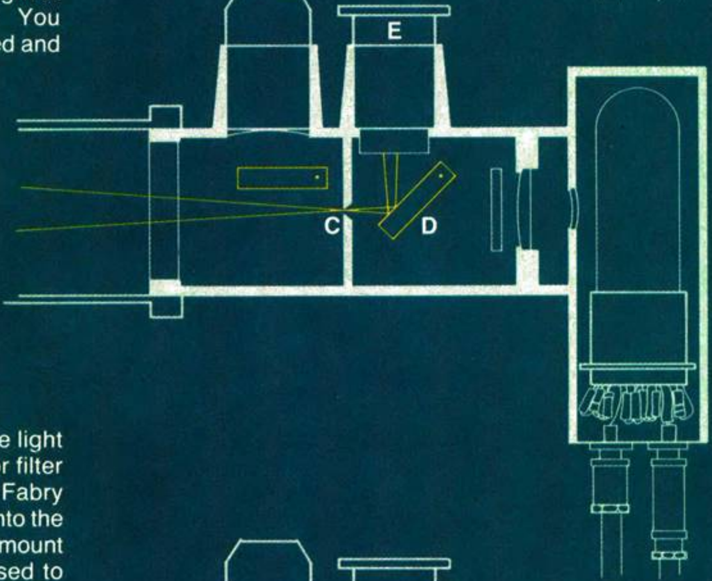


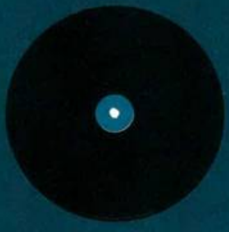


Starfield

Isolating the Object

With the first flip mirror up, light passes through the diaphragm (C) to a second flip mirror (D), which reflects the light to the post-viewing eyepiece (E). You should now see your target isolated and centered in the field of view.

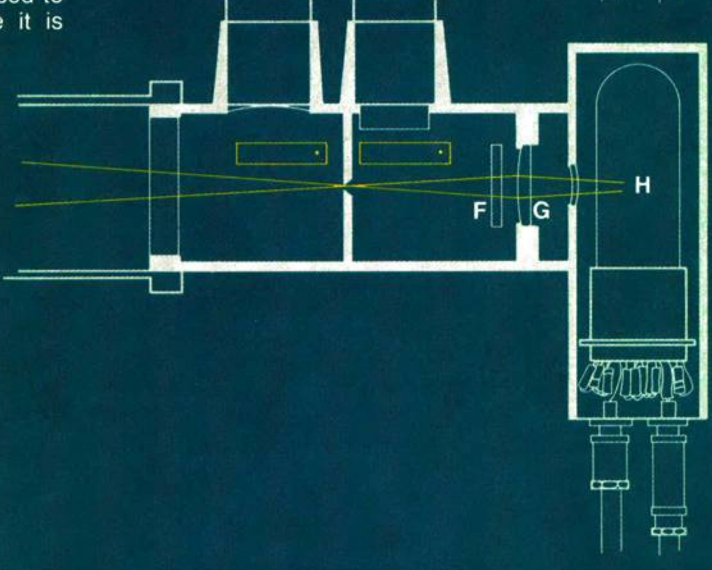




Target Object

Making the Measurement

When both flip mirrors are up, the light is free to pass through the filter or filter wheel (F) and then through the Fabry lens (G), which focuses the light onto the photomultiplier tube (H). A small amount of current is generated and passed to the external electronics, where it is converted into a digital readout.



Digital Readout

Information Resources

Reference Books

Astronomical Photometry by Arne Henden and Ronald Kaitchuck, Van Nostrand Reinhold, 1982.

Photoelectric Photometry of Variable Stars by Douglas Hall and Russell Genet, IAPPP, 1982.

Solar System Photometry Handbook, edited by Russell Genet, Willmann-Bell, 1983.

Suppliers of Photometers

Hopkins-Phoenix Observatory,
7812 W. Clayton Dr., Phoenix, AZ
85033

Optec, Inc., 199 Smith, Lowell, MI
49331

Thorn-EMI-Gencom, Inc., 23
Madison Rd., Fairfield, NJ 07006

Organizations

American Association of Variable
Star Observers (AAVSO), 25 Birch
St., Cambridge, MA 02138

Association of Lunar and Planetary
Observers (ALPO) Minor Planets
Section, Department of Physics,
Illinois College, Jacksonville, IL
62650

International Amateur-Professional
Photoelectric Photometry (IAPPP),
Dyer Observatory, Vanderbilt
University, Nashville, TN 37235

for several minutes while at the same time your mount must support the weight (typically several pounds, depending on the model) of the photometer.

You will also need slow-motion controls for both right ascension and declination axes, as it is almost impossible to center an object by hand.

Optical constraints on your system are much less stringent. Nearly all telescopes can be equipped to do photoelectric photometry, though the best choice is probably the Cassegrain reflector. Refracting scopes have the greatest problem since light must pass through a glass lens before reaching the photometer, eliminating ultraviolet radiation that is normally measured by one of the standard filters. For the same reason, Schmidt-Cassegrains are not ideal although the corrector lens is thin enough to make the problem minor. (If you never measure light through an ultraviolet filter, there is no problem.) Newtonians do not suffer from this problem, though properly counterbalancing the photometer can take a lot of effort.

The aperture of your telescope is important only in that the larger it is, the more light it gathers. Although a 6- or 8-inch scope will give you access to a large number of objects, that number will increase with aperture size.

A final comment on optical systems: in general, the higher the f/ratio, the better off you'll be. Anything above f/8 is fine — it will allow your photometer components to be comfortably spaced and also reduce the amount of sky background you'll observe; but once you get below f/5, you'll encounter serious difficulties.

The Basic Photometer

Of course, the most important piece of equipment you'll need is the photometer itself. A few models are commercially available at a reasonable cost as well as one kit (the HPO model) that can be put together for even less. If you are mechanically and/or electronically inclined, you might look into building or assembling the photometer yourself.

How does the photometer do its job? Essentially, it converts light into an electric current that is then measured; each component plays a role in the process.

The diaphragm is located in the focal plane of the telescope and normally consists of a wheel with several small holes in it. Its function is to let all the light from a study object through while minimizing any excess. The holes are different sizes to allow for different viewing conditions and can be as small as 20 arcseconds or less on professional models.

The filters are generally organized in the same way as the diaphragm: they are set in a wheel or similar device so that different filters can be brought into the light path. By allowing only light of certain wavelengths to pass through, the filter offers a closer look at the kind of radiation emitted by an object and not just its total brightness. (If you intend to observe brightnesses only, you can get by with just one filter.)

The standard filters for stellar objects are the UBV filters, which refer to the wavelength of peak transmission (U = ultraviolet, B = blue, and V = visual, or yellow). In some cases, two more filters are added: R for red and I for infrared, forming the UBVRI system.

The Fabry lens is the next element. It is placed so that an image of the objective, and not the object, is focused onto the light detector. Since detectors can not be made with uniform light sensitivity, any movement of the object within the diaphragm would otherwise result in a variable output.

The heart of the photometer is the light detector, either a photomultiplier tube or photodiode. Since the former are still more common, we will discuss them. As photons of light strike the surface of the photomultiplier, electrons are liberated in direct proportion to the intensity of light. (The explanation of this photoelectric effect won a Nobel Prize for Albert Einstein.) Unfortunately, the number of electrons released are usually quite small. The photomultiplier is designed so that these photoelectrons are accelerated by an electric field until they strike another sensitive surface. Each impact produces about five electrons and these then undergo the same process, which continues until there are approximately one million electrons for each electron initially produced. These are then collected and sent to the external electronics.

Despite the million-fold amplification, the current produced is still very weak. Outside the photometer itself an amplifier further increases the signal strength until it can be easily recorded. The results can then be output to a strip chart recorder, digital display, or computer.

By now you should have a good idea of what is needed to pursue photoelectric photometry in your backyard. The equipment is relatively affordable and readily available, but there is still much to learn. How do you develop an observing program? What are the step-by-step procedures during an observation? What does the data mean and what should be done with it after it's collected? These are all topics to be discussed next month.

In addition, the International Amateur-Professional Photoelectric Photometry (IAPPP) association is geared toward helping amateurs and professionals communicate with each other. For a $15 membership fee, you will receive a quarterly journal with helpful articles on photometry, suggested observing programs, contact people, and requests from professionals for data. The IAPPP also sponsors half a dozen symposia each year with talks and workshops geared to a wide range of audiences.

You may still be at that crossroad, looking for new observing challenges. If you're willing to invest a lot of time and effort in your pursuit and want personal satisfaction from your efforts, then photoelectric photometry could very well be the answer.

Next Month: Photoelectric photometry of variable stars and minor planets.

Frank J. Melillo lives in Valley Stream, New York, and is a member of the Astronomical Society of Long Island. He has been active in astrophotography and photoelectric photometry for the last several years.

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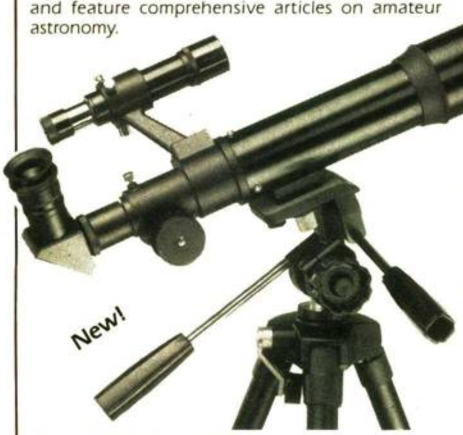

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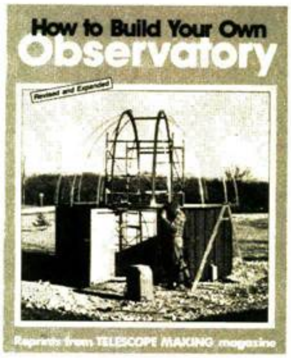

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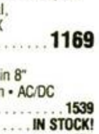

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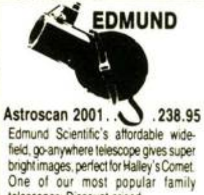

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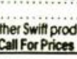

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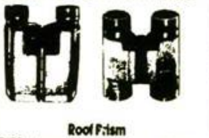

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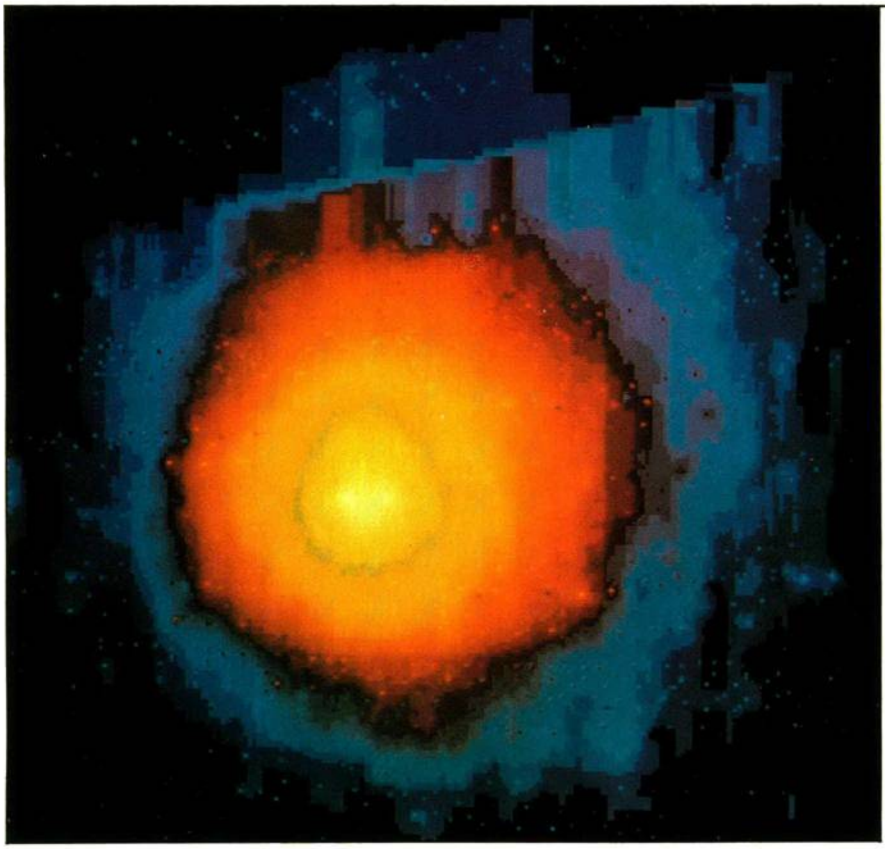


This false-color image of Comet Halley's hydrogen coma was made by the ultraviolet spectrometer on board the Pioneer-Venus Orbiter. Changes in color are the result of a decrease in density from the center outwards, with the coma measuring 34 million kilometers across by 24 million kilometers wide. The direction to the Sun is toward the lower left of the image. NASA/Ames photo.

Comet Halley: The View from Venus

Stimulated by intense solar radiation, Comet Halley reached peak activity around the time of perihelion on February 9. Unfortunately for Earth-based observers, the timing could not have been worse: Halley was lost in the Sun's glare for several days. Although observations from Earth were virtually nonexistent at that time, a fortuitous set of circumstances gave the Pioneer-Venus Orbiter an opportunity to witness the event.

Launched in 1978 to conduct detailed studies of the Venusian atmosphere, the craft was not originally intended for cometary research. But with Venus on the same side of the Sun as the comet during perihelion, project scientists positioned the craft for a series of observations. Successful trial runs with Comet Encke in 1984 and Giacobini-Zinner in 1985 paved the way for Pioneer-Venus to study Halley.

The image shown on this page was taken from February 2 to 5 by the ultraviolet spectrometer on the spacecraft. It consists of 20,000 separate scans across the face of the comet and was processed by a team of computer experts led by Anil Jain at the University of California at Davis.

The different colors represent different brightnesses from hydrogen emission, which steadily decreases away from the center of the comet. Since the brightness is a direct measure of the number of hydrogen atoms along the line of sight, the image shows how hydrogen density decreases. The hydrogen coma is about 34 million kilometers across by 24 million kilometers wide. The asymmetric contours are caused by solar radiation exerting pressure on the hydrogen atoms, pushing them away from the Sun.

According to Ian Stewart of the University of Colorado, the principal investigator for these Pioneer studies, the most surprising result of the Pioneer-Venus observations was the large variability in the water sublimation rate, which was deduced from the observed hydrogen that forms from the dissociation of water. Significant variations occurred from day to day and actually doubled between February 19 and 20, reaching a rate of 60 tons per second. These variations imply that the comet must have a non-uniform surface.

Over the next few months, scientists studying the Pioneer data will seek to determine the rotation rate of the nucleus from regular changes in the water sublimation rate, compare the sublimation rate with Earth-based observations of dust production in the comet, and determine the amount of carbon in the comet and compare its variability to that of water.

Space Telescope Nears Completion

Despite the indefinite hold put on the space program by the Challenger accident last January 28, it is still business as usual at Lockheed's plant in Sunnyvale, California, where the 2.4-meter (94.5-inch) Hubble Space Telescope (HST) is completing a lengthy battery of tests to ready it for launch.

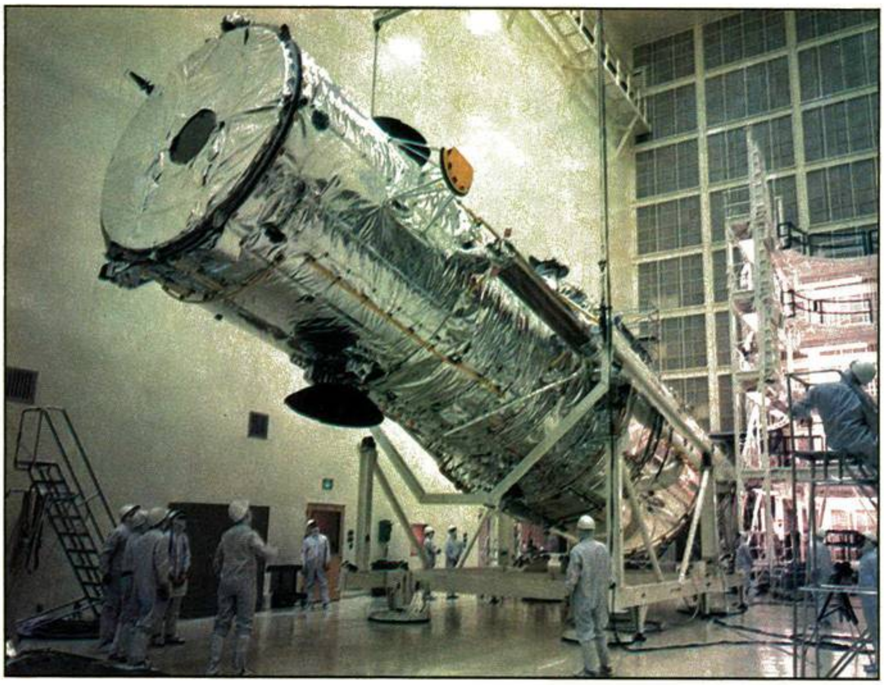
Last February, engineers placed the HST in an acoustic cell and bombarded it with sounds and vibrations that simulated an actual launch. Afterward, tests were run to see if the telescope's performance or structure was impaired.

From there the telescope was given a strenuous forty-day workout in a thermal vacuum chamber, which simulates the conditions of space. Commands were given to the telescope to see how well it would respond in what will be its permanent working environment.

According to Riccardo Giacconi, director of the Space Telescope Science Institute at Johns Hopkins University, NASA intends to launch the telescope as soon as they determine that the Shuttle is safe to fly again.

"We have been assured by NASA that we will be the highest priority within NASA's own programs," said Giacconi last March.

There are, however, at least three other priorities: the possibility of an initial Shuttle test flight to verify the flight



The Hubble Space Telescope in the clean room at Lockheed being readied for testing in the acoustic cell where it will undergo a simulation of launch conditions.

worthiness of any structural changes in the Shuttle system as a consequence of the Challenger accident; Department of Defense missions, which apparently have the highest priority after the test flight; and the launch of a second communications satellite, called the Tracking and Data Relay Satellite, which NASA wants for communication purposes for future missions. Giacconi hopes the telescope can be launched on either the fourth or fifth Shuttle mission after flights resume.

In the meantime, the deadline for submitting HST project proposals has been extended to September 15, 1986. These projects will be reviewed by the Space Telescope Science Institute and 200 will be selected to occupy the telescope's first year of operation. The selection process will be repeated annually.

Third Black Hole Discovered

Observations of the x-ray nova A0620-00 in the constellation Monoceros have revealed what appears to be a black hole, the nearest to Earth yet found. Discovered by Jeffrey McClintock of the Harvard-Smithsonian Center for Astrophysics and Ronald Remillard of the Massachusetts Institute of Technology, it is only the third stellar black hole recognized to date.

X-ray novae and their more common relatives, x-ray binaries, consist of a gravitationally *collapsed* star (a neutron star or a black hole) in mutual orbit with an ordinary star. When material from the normal star is drawn into the gravitational well of the compact object, it is greatly heated and begins to emit x-rays. If conditions are right, a large amount of material may heat at once and set off a huge explosion — what we see as an x-ray nova.

In most x-ray novae, the optical spectrum of the normal star is overwhelmed by the powerful x-ray source. Luckily, this is not the case with A0620-00, meaning astronomers can analyze the spectrum to determine the age, distance, and orbital parameters of the system.

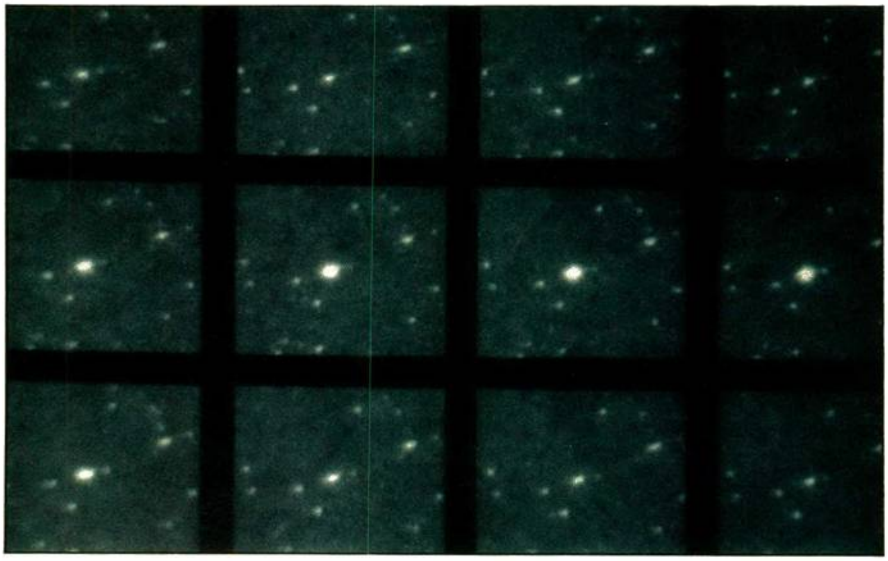
McClintock and Remillard announced their discovery at the January 1986 meeting of the American Astronomical Society in Houston, Texas. Their analysis shows the system is 1,000 parsecs from Earth and consists of an ordinary K-type dwarf, slightly cooler and less massive than the Sun, that orbits a massive companion every 7.8 hours at a rate close to 500 kilometers per second. These orbital characteristics can be satisfied only if the unseen companion has more than three times the mass of the Sun. Because a neutron star of this mass cannot exist (since its structure cannot support that much weight), the inevitable conclusion is that the compact component must be a black hole.

A0620-00 thus joins Cygnus X-1 and LMC X-3 as the only known stellar black holes, all of which were discovered through their x-ray emissions and dynamical effects on a binary companion.

Gamma Ray Source Pinpointed

For years astronomers have theorized that certain stars experiencing an increase in matter — through accretion from a companion star, for example — might reach a critical stage where they suddenly burn up this excess matter in one fell swoop, releasing energy in the form of gamma rays. To Earth-based observers, such stars would signal this rapid burning by a single, rapid flash of visible light.

The problem with proving the existence of optical gamma-ray bursters is that no one knows when or where the next one will flash. Although suspected gamma-ray burst sites have been detected (see "Chasing the Ogre," Gazer's Gazette, January 1986), specific targets have never been located . . . until now.



This sequence of photographs shows the bright star Beta Camelopardalis (in the center of each frame) and the optical burst that took place near it in 1969. The flash can be seen brightening in the third and fourth frames of row one and reaching maximum in the sixth through eighth frames.

Reporting in the August 1, 1985 issue of the *Astrophysical Journal*, astronomers Thomas J. Wdowiak of the University of Alabama and K. Stuart Clifton of NASA's Marshall Space Flight Center believe they have identified a gamma-ray burster near the yellow supergiant Beta (β) Camelopardalis, possibly originating from an unseen companion of that star.

The flash, which lasted exactly one-fifth of a second, was detected on a videotape made during television observations of meteors and aurorae from a NASA aircraft flying over northern Canada in 1969. The patrol tapes were recently pulled and examined in order to look for and pinpoint these unexplained optical bursts.

"Now we have a signpost," says Dr. Wdowiak. "We can watch Beta Cam and its immediate vicinity to see if the flash occurs again."

Wdowiak says the burst took place within a volume of space roughly 64,000 kilometers in diameter and briefly outshone Beta, which is 6,000 times more luminous than the Sun. The astronomer calculates that an estimated 15 billion tons of material was suddenly converted into energy.

"That kind of energy could be released by dropping matter, such as that drawn from another star, into an extremely strong gravitational field and 'hitting bottom,'" says Wdowiak. The bottom, he adds, could be the surface of a white dwarf, neutron star, or the event horizon of a black hole.

EXOSAT Racking Up More Discoveries

After three years in orbit, EXOSAT, the European X-Ray Observatory Satellite, has more than proven its worth. It has made over 2,000 cosmic x-ray observations resulting in a number of significant discoveries.

The success of the 400-kilogram satellite is attributable to both its array of sophisticated instrumentation and its unusually high northern orbit (intially, a 195,000-mile apogee). This gives EXOSAT about 100 hours of virtually uninterrupted viewing time during each orbit, something that was impossible with earlier near-Earth satellites.

As reported in the February 6, 1986 issue of *Nature*, EXOSAT's results have greatly enriched the domain of x-ray astronomy. The satellite recently completed a detailed study of the narrow galactic ridge and identified a number of bright supernova remnants as well as suspected x-ray binaries, some of which are new discoveries. One x-ray source, EXO0748-676, was discovered while the satellite was slewing to a new target.

One of the most exciting EXOSAT results was the discovery of quasi-periodic oscillations (QPOs) in several low-mass x-

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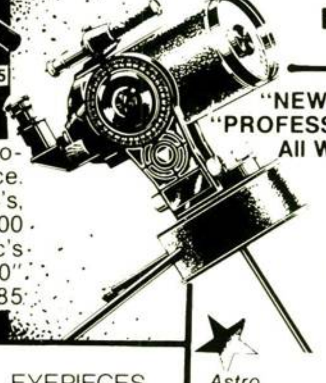

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ray binary stars. As opposed to regular pulses of energy detected from spinning neutron stars, QPOs are characterized by fluctuations in x-ray intensity that are directly dependent on the total energy emitted by the source. QPOs become evident when the source's apparent luminosity is either very bright or very faint, but not at intermediate stages. Astronomers speculate that the fluctuations probably indicate a complex instability in the flow of matter from a normal star onto a more compact object. So far, about seven sources are known to display this phenomenon.

In addition, EXOSAT has observed an unusual burst of x-rays from Cir X-1, an x-ray source previously thought to be a black hole in the constellation Circinus. However, since x-ray bursts appear to be associated only with neutron stars, Cir X-1 will probably need to be redesignated.

EXOSAT has also peered beyond the Milky Way at the nuclei of "active galaxies," from which large amounts of energy are being released from a compact source. Observations have been made of both "soft" x-ray excesses in extragalactic sources, as well as those manifesting more energetic changes. In one type of luminous galaxy, designated PKS 2155-304, the x-ray luminosity increased from 1.5 x 10^{45} to 10^{46} ergs per second in about fifty minutes. Unless relativistic effects are occurring, astronomers estimate that mass must be converting to energy at a conversion efficiency exceeding 50 percent.

Perhaps the most impressive fact about EXOSAT is that it would have taken about five years of near Earth-orbit observations to produce the same quantity of data that the satellite has produced in only two years. The database now being assimilated, which will take years to investigate, will likely produce even more surprises.

VLA To Be Modified For Neptune Encounter

The Very Large Array, the world's largest radio telescope, is being fitted with new receivers to give scientists more and better pictures of Neptune when Voyager 2 encounters that planet in 1989.

Signals sent back to Earth from Neptune will be the weakest ever received from a spacecraft. Scientists realized some time ago that the Deep Space Network, operated for NASA by the Jet Propulsion Laboratory in Pasadena, California, would require more signal-collecting area if quality pictures of Neptune were to be received. Fitting the VLA with new receivers will double the combined collecting area when used with the Goldstone Deep Space Communications Complex near Death Valley, California.

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benefit," said Dr. Paul Vanden Bout, director of the National Radio Astronomy Observatory (NRAO). "It not only will enhance the science we get from Neptune, but it also will increase our radio astronomy capabilities after the flyby is over."

The VLA radio telescope, located near Socorro, New Mexico, is part of the National Radio Astronomy Observatory, which is funded by the National Science Foundation. The telescope consists of a Y-shaped configuration of twenty-seven radio antennas, each measuring 82 feet in diameter.

Voyager 2 may come within 3,520 kilometers of Neptune's surface, much closer than the 78,400-kilometer encounter with Uranus. The nearness of this flyby and the signal enhancement obtained from the VLA are expected to give scientists the same quality pictures of Neptune as those received of Uranus and its satellites even though the signals will be coming from a billion miles farther out in space.

The new receivers are being funded by NASA at a cost of $5.5 million and are being built at the NRAO's Central Development Laboratory in Charlottesville, Virginia. The equipment should be installed and ready for testing by early 1989 in time for Voyager 2's scheduled encounter with Neptune on August 24, 1989.

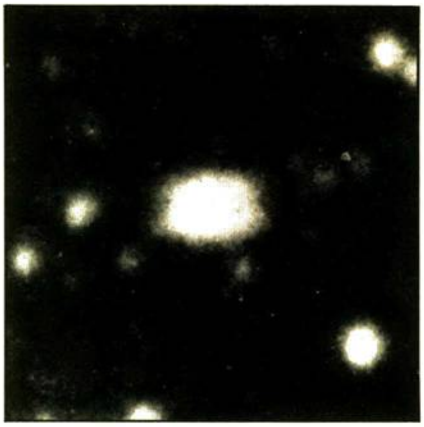
Neptune, the eighth planet from the Sun, is slightly smaller than Uranus. The planet has two known moons; whether Voyager 2 will find others remains to be seen.

Gomez' Nebula is Rare Find

A discovery in May 1985 by astronomers at Cerro Tololo Inter-American Observatory in Chile has added a new shape to the growing morphological hodgepodge of non-stellar objects. Enter Object Gomez, unofficially dubbed the "Hamburger Nebula."

The object was named for Arturo Gomez, a Chilean assistant observer at Cerro Tololo, who made the discovery with the observatory's 1.5-meter telescope. Located in Sagittarius, the object appears as a flattened smudge of light measuring 3 by 5 arcseconds. It is divided horizontally by what is speculated as being an equatorial dust band, making the object resemble a luminous hamburger seen edge-on.

Initially, astronomers thought the object was an edge-on galaxy and the equatorial division was simply the kind of dust band that commonly surrounds most spiral galaxies. This idea was overruled, however, because there are few galaxies in this region that are bright enough to shine through the dense, dusty center of the Milky Way. Moreover, spectra of the object indicated that it was a normal star somewhat hotter than the Sun. Adding to the confusion were infrared measurements taken by astronomer Kimiaki Kawara of Japan, which revealed that the star is not hot but cold, at least ten times colder than previous spectra readings show.



Object Gomez may be our first view of a planetary nebula in the making. Photo courtesy of National Optical Astronomy Observatories.

Astronomers now believe that Object Gomez is a star surrounded by an equatorial dust ring thick enough to hide part of the star from view. The hot (blue) emissions observed spectroscopically are attributed to dust in the star's polar regions that scatter light back toward Earth. The star has evolved away from the main sequence, past the supergiant stage, and is presently undergoing a rapid transition toward becoming a planetary nebula. If this is the case, Object Gomez may offer astronomers an unprecedented look at a dying star just beginning to cast off its outer gas shell into space.

Quasar Gas Envelope Detected

Quasar 3C275.1 was the first quasar to be found at the center of a rich cluster of galaxies. Confirmed in 1984, this discovery supported the concept that quasars are extremely luminous objects located at vast distances from Earth and are not relatively nearby objects, as some astronomers have proposed.

The quasar was also known to be surrounded by an elliptical nebulosity, which had been suspected of being a giant galaxy. Recent findings by Paul Hintzen of NASA-Goddard and John Stocke of the University of Arizona have shown this is not the case.

Spectra taken by these researchers at Kitt Peak National Observatory in Arizona indicate that the nebulosity is actually a rotating gas cloud 100,000 parsecs in diameter. Since its characteristics are inconsistent with those of a spiral galaxy, Hintzen and Stocke suggest that the gas originated in the surrounding cluster of galaxies and is now falling toward the quasar. Many scientists believe that quasars derive their energy from matter falling into a supermassive black hole. If true, this gas cloud may ultimately feed such a black hole.

AstroCalendar

June 6-7
Burke Lake Telescope Meet, Burke, Virginia. Contact: John S. Huggins, 5608 Flag Run Dr., Springfield, VA 22151.

June 19-21
IAPPP Symposium on Photoelectric Photometry, Mercyhurst College, Erie, Pennsylvania. Contact: Robert C. Reisenweber, Rolling Ridge Observatory, 3621 Ridge Parkway, Erie, PA 16510. Phone (814) 899-2560.

June 22-27
168th Meeting of the American Astronomical Society (professional meeting), sponsored by Iowa State University, Ames, Iowa. Contact: AAS, 1816 Jefferson Pl., N.W., Washington, DC 20036.

June 27-30
Royal Astronomical Society of Canada General Assembly, Winnipeg, Manitoba, Canada. Contact: Lorence Mlodzinski, Registration Committee, R.A.S.C. General Assembly 1986, P.O. Box 174, St. James Post Office, Winnipeg, Manitoba, Canada R3J 3R4.

June 29-July 4
International Planetarium Society Eighth Biennial Conference, Tucson, Arizona. Contact: IPS Conference Committee, Flandrau Planetarium, University of Arizona, Tucson, AZ 85721. Phone (602) 621-4515.

July 11-13
Annual Convention of the Northwest Region of the Astronomical League (sponsored by the Seattle Astronomical Society), Seattle, Washington. Contact: Bob Suryan, Seattle Astronomical Society, 6710 - 4th Ave. NW, Seattle, WA 98117. Phone (206) 789-0599.

July 11-13
16th Annual NFCAAA Summer Seminar, Darling Hill Observatory, Vesper, New York. Contact: Denise Sabatini, 342½ Chestnut St., North Syracuse, NY 13212. Phone (315) 458-1454 evenings and weekends.

July 12-17
98th Annual Meeting of the Astronomical Society of the Pacific, University of Colorado, Boulder, Colorado. Contact: A.S.P., 1290 24th Ave., San Francisco, CA 94122. Phone (415) 661-8660.

July 16-24
Space Week '86. Contact: James B. Harris, Jr., Florida Space Week Committee, P.O. Box 291, Sharpes, FL 32959. Phone (305) 632-9139.

July 24-27
Yellowstone's Night Skies (4-day course), Yellowstone National Park, Wyoming. Contact: Gene Ball, Yellowstone Institute, P.O. Box 117, Yellowstone National Park, WY 82190. Phone (307) 344-7381 ext. 2384.

July 31-August 4
3rd Annual Mount Kobau Star Party (superb observing, telescope-making and astrophotography contests, speakers), Okanagan Valley, British Columbia. Contact: Peter Kuzel, 4100 25th Ave., Vernon, B.C., Canada V1T 1P4. Phone (604) 545-1226.

August 5-10
ASTRO CON 86 (national convention of the Astronomical League), Baltimore, Maryland. Contact: ASTRO CON 86, 642 Kingston Rd., Baltimore, MD 21220.

August 8-10
STARFEST '86 (fifth annual observing convention of the North York Astronomical Association), River Place Campground, Mount Forest, Ontario, Canada. Contact: Andreas Gada, 145 St. George St., Apt. 701, Toronto, Ontario, Canada M5R 2M1.

August 10-12
Star Trails West (2-day class), Yellowstone National Park, Wyoming. Contact: Gene Ball, Yellowstone Institute, P.O. Box 117, Yellowstone National Park, WY 82190. Phone (307) 344-7381 ext. 2384.

September 5-7
ASTROFEST (sponsored by the Chicago Astronomical Society), Camp Shaw-Waw-Nas-See Campsite, Illinois. Contact: Astrofest, P.O. Box 596-A, Tinley Park, IL 60477. Phone James Hansley, Chairman, (312) 764-5131.

October 2-5
Okie-Tex Star Party (sponsored by the Oklahoma City Astronomy Club), Lake Murray, Oklahoma. Contact: Joe Pearson, 700 Teal Place, Edmond, OK 73034.

Meeting notices to appear in AstroCalendar must be submitted at least four months in advance of the meeting date. Most organizations appreciate your enclosing a long (business-size) self-addressed, stamped envelope along with your request for information.

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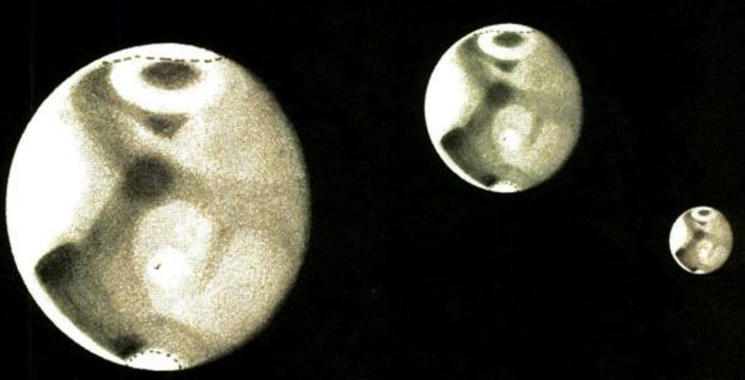
Gazer's Gazette

Springtime on Mars: A Rare Opposition

The Varying Apparent Diameters of Mars



Mars' telescopic disk as seen when farthest from Earth (right), at a median distance (middle), and during perihelic opposition. Richard J. McKim drawings.

In the southern hemisphere of Mars, it is springtime. Though blooming flowers, buzzing bees, and tranquil blue-sky days don't exist there, that part of the desolate planet is, in a sense, coming back to life. Far from being a static desert planet, Mars is a world of sudden and dramatic changes, changes that are especially visible in a telescope as the planet draws nearer to the Sun and Earth, growing larger and brighter in the night sky. But unlike past Martian spring seasons, this spring is a particularly good time to observe Mars because it will be closer to Earth than it has been in fifteen years.

As seen from Earth, no other planet undergoes as dramatic a change as Mars. When it is most distant from Earth and approaching the far side of the Sun, the planet appears as a featureless orange disk not much larger than Uranus. Its minimum magnitude is 1.4, slightly fainter than Deneb in Cygnus the Swan.

But then, roughly once every 780 days, Mars reaches opposition — a straight-line configuration of the Sun, Earth, and Mars with Earth positioned in between. At this time, Mars' ocher-hued disk is closest and grows large in apparent diameter. It can briefly rival Venus and Jupiter in brightness.

In a 3-inch refractor or 6- to 8-inch reflector, Mars is most interesting at opposition. It is a world of changing seasons and light, where yellow clouds of dust periodically cover the planet and then, weeks later, dissipate over the rust-red surface where a bright south polar cap gradually shrinks as vague, gray-green surface blotches darken.

Observers who see Mars for the first time during these favorable periods often become Mars observers for life, while others who remember Mars as nothing more than an orange dot in the eyepiece wonder what all the fuss is about. Perhaps these disgruntled individuals observed the oppositions of 1965 or 1980 when Mars was high in the sky but still rather faint and showing very little telescopic detail. Understandably, they may wonder why Mars looked so exciting to other observers but not to them.

The point is that no two successive oppositions of Mars are alike: some are better than others. Why is this? Isn't opposition supposed to be the best time to observe an outer planet because it is both near Earth and exactly opposite the Sun in the sky? Usually the answer is yes, but Mars is a more complex case.

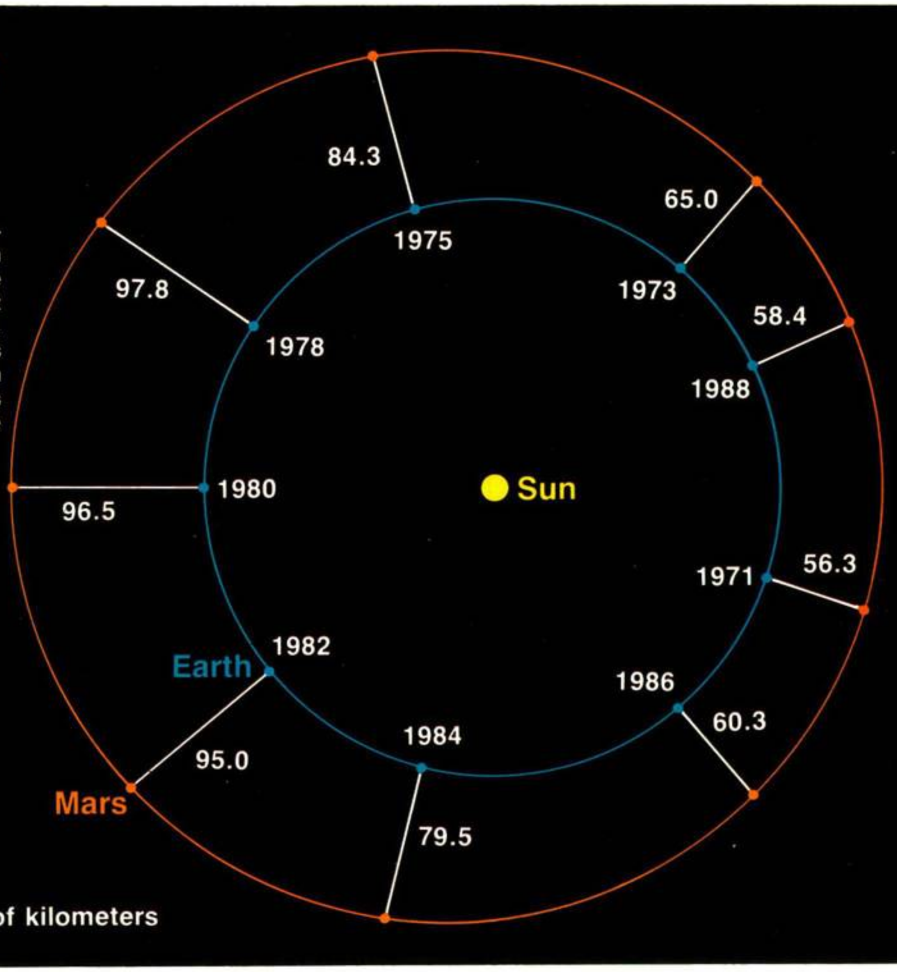
Because Mars' orbit is more eccentric than Earth's, meaning its distance from the Sun varies more than Earth's, Mars reaches opposition at varying relative distances from the Earth and Sun. The same thing happens to Jupiter and Saturn, but they are so distant and in such near-circular orbits that the effect is minimal. From opposition to opposition, the Mars-Earth and Mars-Sun distances gradually close until finally Mars reaches an opposition when it is both nearing its closest approach to the Sun (perihelion) and lined up 180° with the Sun and Earth. Called perihelic opposition, this is the most favorable time to observe Mars. The oppositions occurring July 10, 1986, and September 28, 1988 are perihelic oppositions. (In 1988, Mars will come closer to Earth and will appear slightly brighter.) Perihelic oppositions occur at intervals of 15 and 17 years, making them rare events that are eagerly anticipated by planetary observers.

At subsequent oppositions, the Mars-Earth and Mars-Sun distances correspondingly increase until Mars reaches aphelic opposition (aphelion being the point in a planet's orbit that is farthest from the Sun.) On these occasions, even though Mars is exactly opposite the Sun in the sky, it is farther from the Sun and Earth than it is at perihelic opposition so it presents a smaller, fainter disk.

Another factor to consider is that although Mars reaches opposition on July 10 this year, it won't be closest to Earth until six days later, approximately 458,000 kilometers closer than at opposition. The reason is that although the Sun, Earth, and Mars will be aligned 180° on July 10, Mars reaches perihelion on September 25. Consequently, as Mars' orbit continues

The Different Oppositions of Mars

It is easy to see why some oppositions are better than others. In 1980, Mars was farthest from the Sun (aphelion) and at its farthest opposition-distance from Earth. This year, and again in 1988, Mars will be at its nearest point to the Sun and Earth, making these two years excellent times to observe the planet.



Distances are in millions of kilometers

bringing it closer to the Sun, a component of that movement is also bringing it closer to Earth. Then, six days after opposition, Earth — with the advantage of an inside orbital track — begins pulling ahead of Mars, outrunning that planet's more leisurely pace.

All perihelic oppositions occur when the planet is south of Earth's celestial equator. Unfortunately, the July 10 opposition occurs particularly far south this year; in fact, it occurs at Mars' lowest southern declination of −28° when the planet will be visible just east of the handle of the Teapot asterism in Sagittarius. For observers at about 45° north latitude, Mars will be only about 17° above the horizon when it crosses the meridian around midnight on the 10th; for observers in the middle latitudes, the planet will be about 27° above the horizon. Observers in the Northern Hemisphere should not give up before they have at least trained a telescope on Mars.

Mars will be at its best from mid-May to the end of September, with a maximum angular diameter of 23.2 arcseconds and a magnitude of about −2.6 by July 16. Keep in mind that because the Martian day is only 40 minutes longer than Earth's, a particular feature observed crossing the planet's central meridian on one night crosses the central meridian 40 minutes later the following evening. This amounts to about a 10° lag per day. Over a period of 36 days, you should be able to observe all longitudes of Mars, if your skies are clear!

Equipment for Observing Mars

Ideally, to observe Mars you should use telescopes no smaller than a 3-inch refractor or a 6- to 8-inch reflector. Telescopes with apertures larger than 10 inches may actually be a disadvantage since they can better resolve air currents on nights of unsteady seeing, causing wavering images. If you plan to make sketches or photographs, an equatorial mount with a clock drive is essential.

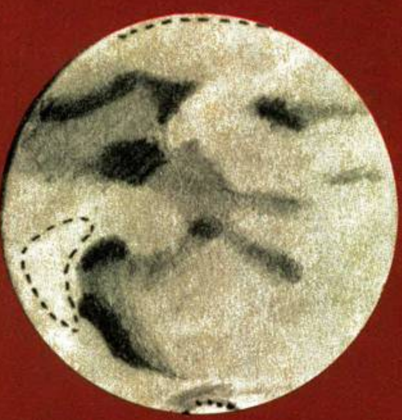
Magnification is an important factor, too. At this opposition, the planet's angular diameter will reach 23.2 arcseconds, roughly half the mean size of Jupiter. Fairly high power is needed for detailed observations. As a starting point, use magnifications of 30 to 40 times the diameter of your telescope's objective. Use only high-quality eyepieces; orthoscopics and Plossls are recommended for their color correction and eye relief. Make sure your telescope is well collimated and has had time to cool down to the ambient air temperature before observing.

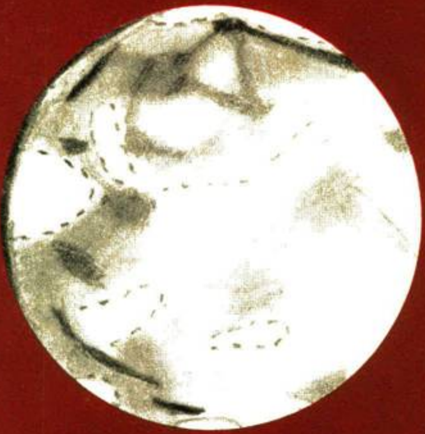
If you want to make detailed studies of Mars' surface and cloud features, or you simply wish to observe those features that are masked by the planet's bright light, consider using color filters. At first glance, Mars may appear to be a featureless, orange globe. Through color filters, however, certain "hidden" details can be revealed.

Most filters or filter material are available from optical dealers and some photo supply stores. They come in the form of gelatin sheets or tinted or coated glass. The gelatin sheets can be cut and mounted in a sturdy 35mm slide frame. To use them, simply hold the filter between your eye and the eyepiece. Gelatin filters have the advantage of being inexpensive, but they are soft; fingerprints and smudges are difficult to remove without scratching the filter's surface. They also require that you hold the filter in one hand during observing, which is inconvenient if you are trying to sketch the planet.

A better alternative is the more expensive glass filter, which normally comes threaded for eyepiece attachment. Overall, glass filters are more practical and of a higher quality than gelatin filters. Consequently, they are widely used in observational astronomy.

Color filters transmit colors like themselves and absorb their complimentary, or opposite, colors. For example, the Martian surface absorbs mainly blues and greens and reflects reddish-orange hues. But a red filter transmits this predominant color and

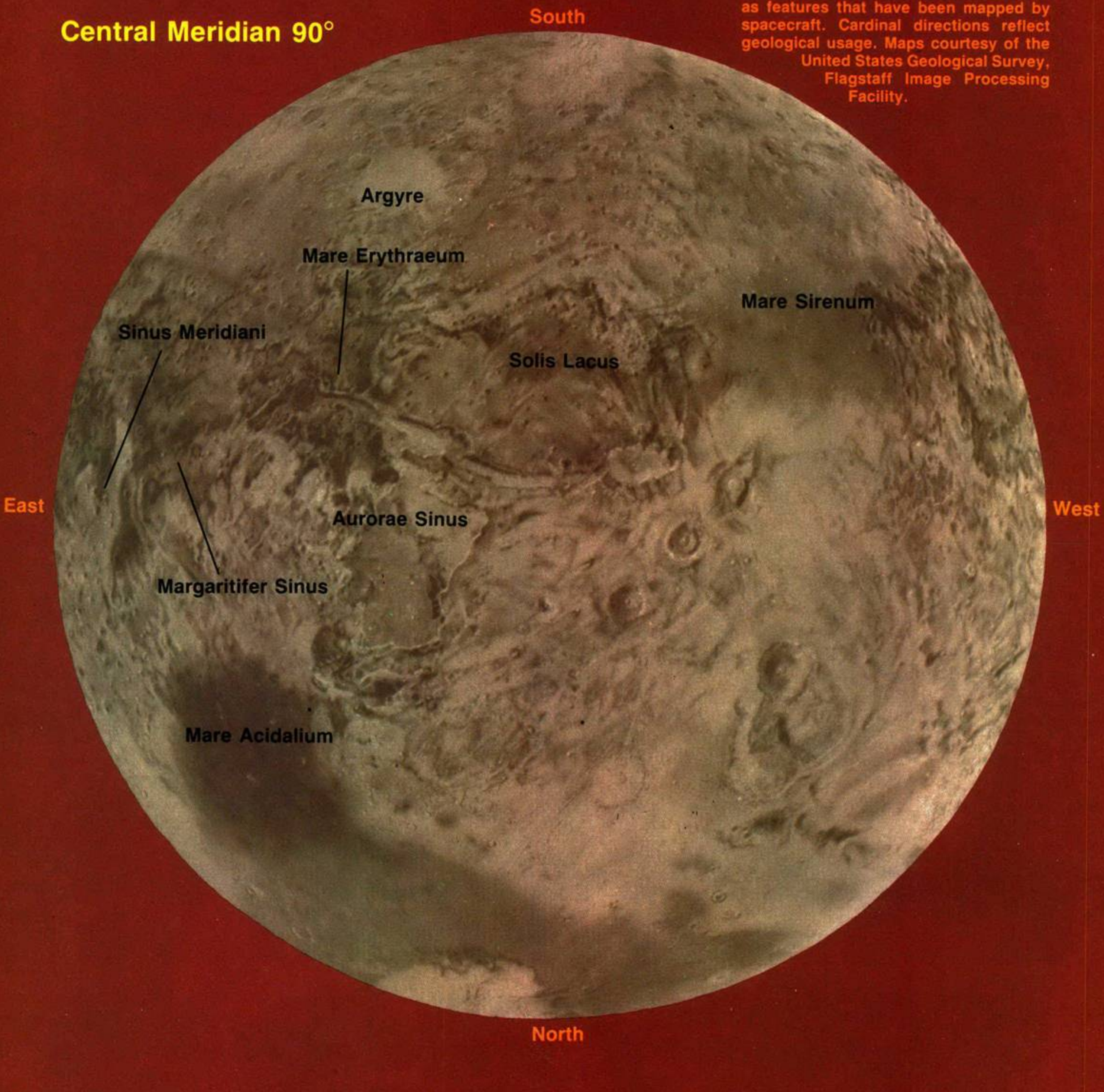




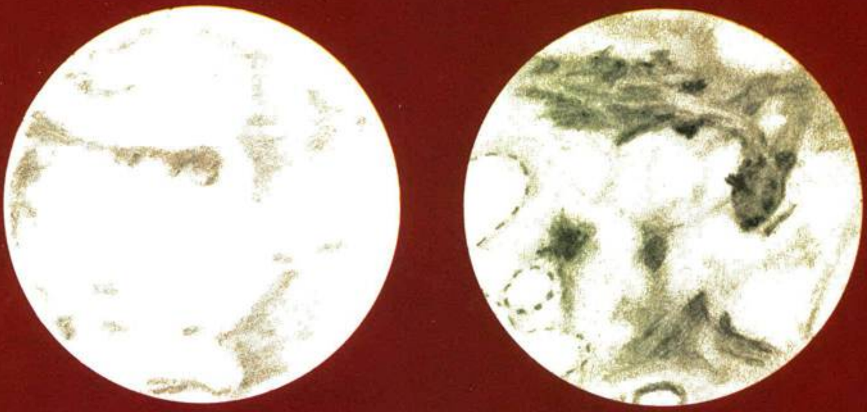
Far Left: In this sketch by Morimasa Nakajima, the dark feature at upper left is Mare Erythraeum, and Solis Lacus is the round feature below that. Part of Mare Acidalium is also shown at lower left. The dotted line indicates a bright cloud feature. Left: A similar view made 19 days later by Donald Parker. Less detail is visible in Solis Lacus and several cloud formations have been demarcated.

These maps show Martian features most visible with Earth-based telescopes as well as features that have been mapped by spacecraft. Cardinal directions reflect geological usage. Maps courtesy of the United States Geological Survey, Flagstaff Image Processing Facility.

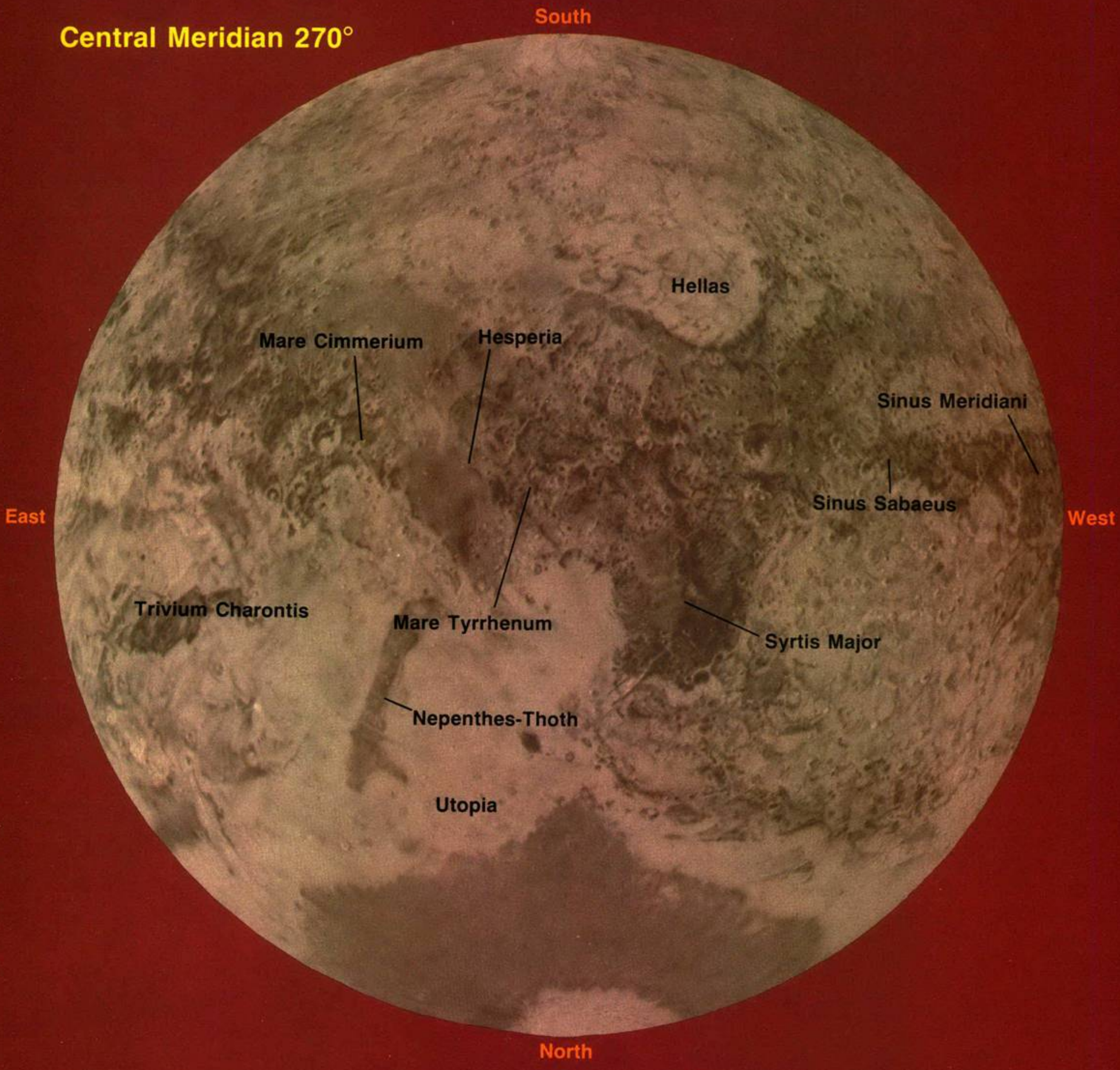
Central Meridian 90°

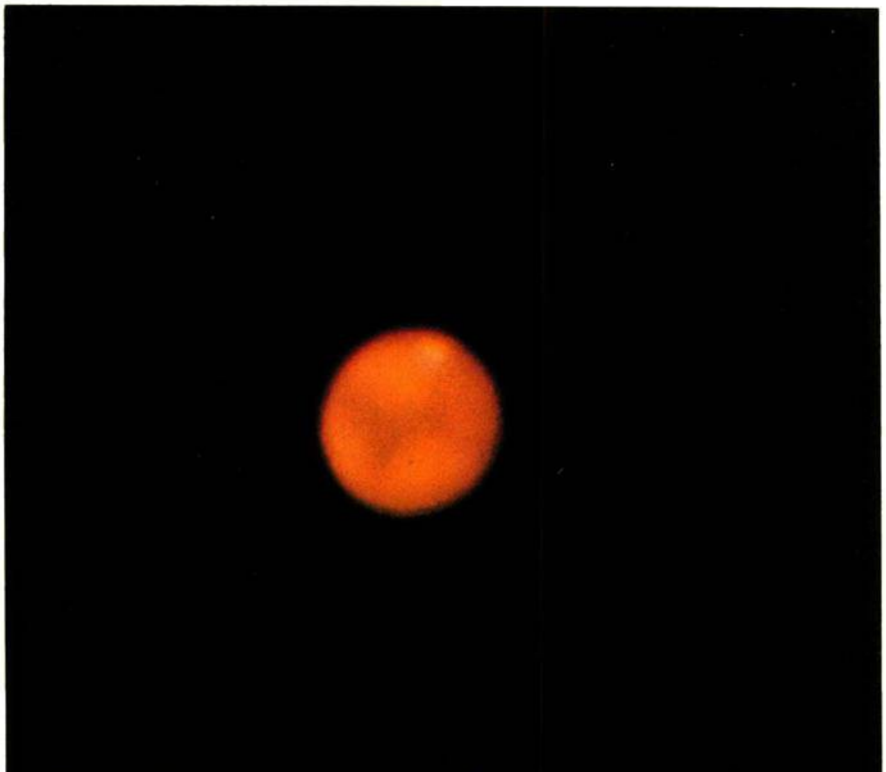

South
Argyre
Mare Erythraeum
Mare Sirenum
Sinus Meridiani
Solis Lacus
East
West
Aurorae Sinus
Margaritifer Sinus
Mare Acidalium
North

Far Right: Thomas Dobbins and Kenneth Schneller depicted Syrtis Major as the dark angular feature right of center, with Mare Tyrrhenum and Hesperia stretching to the left. (Right) Nine days earlier, Carlos Hernandez could easily see Sinus Meridiani on the central meridian and part of Margaritifer Sinus to the right. Mare Acidalium is partly visible at the lower right.



Central Meridian 270°


South
Hellas
Mare Cimmerium
Hesperia
Sinus Meridiani
Sinus Sabaeus
East
West
Trivium Charontis
Mare Tyrrhenum
Syrtis Major
Nepenthes-Thoth
Utopia
North



Mars as it will look at opposition on July 10. The south pole (top) is inclined toward Earth and shows a bright polar cap. Syrtis Major is the dark triangular feature left of center; to the right stretches Sinus Sabeaus; to the left Mare Tyrrhenum. This photo was taken August 30, 1971 (near Mars' last perihelic opposition) by Steve Reed using an 8-inch telescope and eyepiece projection.

absorbs the blue and green features, consequently darkening them. In this way, a color filter acts to improve image contrast, increasing the brightness differential between colors that are present on the planet.

Experienced observers recommend a number of different color filters for observing Mars. The most popular are the red Wratten 25A and the orange Wratten 21, with peak transmissions of 617 and 593 nanometers, respectively. (A nanometer is a unit used in measuring the various wavelengths of light. The longer wavelengths of red and orange light have higher values and the shorter wavelengths of green and blue light have lesser values. One nanometer equals one-billionth of a meter.) One of the best all-around filters for enhancing both surface features and clouds is a magenta Wratten 30, recently manufactured by VERNONscope.

Filters of other colors enhance features at consecutively higher altitudes. For example, yellow and green filters are useful for looking at Martian ground fog, haze, and the yellow clouds kicked up by dust storms; blue-green and blue filters reveal clouds at mid-altitudes; and violet filters pass light that reflects from high-altitude ice clouds and haze.

Deserts, Dust, and Clouds

One of the exciting things about observing Mars is that some of its geographical features are visible in small telescopes. These features can be used as points of reference in monitoring the climatic changes in the planet's atmosphere, which are more overt in the southern hemisphere at the onset of Martian spring, occurring around June 1 this year. Mars' southern spring and summer always occur around perihelion. Although the seasons are shorter than they are at aphelion, they are much warmer. (Consider that from perihelion to aphelion, the distance between the Sun and Mars varies by about 40 million kilometers, while the distance between the Sun and Earth varies by 6.5 million kilometers.) Thus Mars' southern hemisphere is subjected to greater extremes in climate, which causes global dust storms, darkening of the maria, and the subtle ice clouds that appear in the upper atmosphere.

At low magnifications, little if any surface detail can be seen on Mars. The planet appears as a soft, orange disk perhaps showing a bright dot of white at the southern pole, which is the polar cap. Moderate magnifications improve the view only slightly, although the polar cap will be more noticeable and the uniform orange hue will appear broken by vague, dark patchy areas.

Only with fairly high magnification can one fully appreciate what Mars has to offer: the polar cap, the clouds, and the surface features.

The Polar Caps

Since it is now springtime in the southern hemisphere on Mars (the "top" part of the planet in the telescopic view), the north pole is pointed away from Earth and won't be highly visible. Though the south pole will be inclined toward Earth, the inclination amounts to only about 3.5° on July 10 so the view of that region will not be optimal. The inclination increases to 11° by October. Since Mars will still be relatively nearby, we should have a fine view of the thawing of the southern polar cap.

As the southern hemisphere warms up, the polar cap will begin to shrink. If you observe it for several weeks, you will notice the change. The edge of the polar cap is often surrounded by a dark ring that is visible into Martian summer, which begins October 25. In the weeks following opposition, you might also look for rifts and other irregularities at the edge of the polar cap and extending into the surrounding plains.

The shrinking of the polar cap is often a precursor to meteorological activity and change. As spring progresses, clouds and mists appear around the polar region as well as in regions located in the upper mid-latitudes of the southern hemisphere, such as the Hellas basin area (see maps on pages 82 and 83). The meteorological force involved seems to be convection caused by the thawing of the polar cap. As the white polar cap melts and shrinks, the amount of light reflected is reduced and the planet's surface begins absorbing more heat. As the surface heats, this causes powerful convective wind currents. It is this rapid transfer of heat that is considered to be one of the causes of the huge dust storms that occur in late spring on Mars.

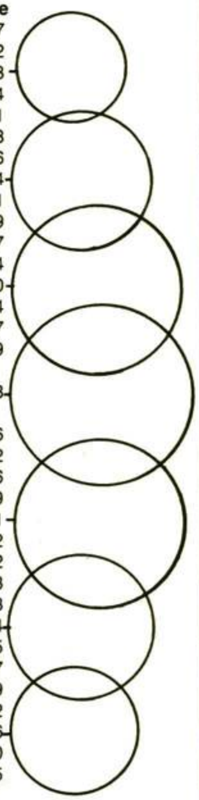
The Clouds of Mars

One thing Mars has in great quantity is dust and sand. It would be a harrowing sight indeed to be standing on some stumpy 100-meter-high sandblasted mesa in the Valles Marineris, looking out over the vast rust-red landscape at an approaching wall of churning, pink-brown dust several hundred meters high. Although the view from Earth may not be as thrilling, it is nonetheless interesting to behold this spectacle from the safe distance of 58 million kilometers.

The great global dust storms occur mainly in the southern hemisphere when Mars is nearing perihelion, though both the Mariner and Viking missions supplied evidence of more localized dust storms in the winter months. Rapid heat transfer can accelerate Martian winds in excess of 300 kilometers per hour. On a desert planet, this means that dust and sand will be lofted into the air very rapidly. In a telescope, you know you are looking at a dust storm when the surface features that were so obvious on the previous night have abruptly disappeared beneath a diffuse, yellow haze.

Ephemeris for Mars

Date	Distance	Magnitude	Diameter	Phase
May 10	0.698	−0.9	13.4	0.907
May 14	0.668	−1.0	14.0	0.912
May 18	0.639	−1.1	14.6	0.918
May 22	0.611	−1.2	15.2	0.924
May 26	0.585	−1.4	15.9	0.931
May 30	0.560	−1.5	16.6	0.938
June 3	0.536	−1.6	17.4	0.946
June 7	0.520	−1.7	18.8	0.954
June 11	0.494	−1.9	18.9	0.961
June 15	0.475	−2.0	19.6	0.969
June 19	0.459	−2.1	20.3	0.977
June 23	0.444	−2.3	21.0	0.984
June 27	0.431	−2.4	21.6	0.990
July 1	0.421	−2.5	22.2	0.994
July 5	0.413	−2.6	22.6	0.997
July 9	0.407	−2.6	22.9	0.999
July 10	Opposition			
July 13	0.404	−2.7	23.1	0.998
July 16	Closest Approach			
July 17	0.403	−2.6	23.2	0.996
July 21	0.405	−2.6	23.1	0.992
July 25	0.408	−2.5	22.9	0.986
July 29	0.414	−2.4	22.5	0.979
Aug. 2	0.422	−2.3	22.1	0.971
Aug. 6	0.431	−2.3	21.6	0.962
Aug. 10	0.443	−2.2	21.1	0.952
Aug. 14	0.456	−2.1	20.5	0.943
Aug. 18	0.470	−2.0	19.9	0.933
Aug. 22	0.485	−1.9	19.2	0.924
Aug. 26	0.502	−1.8	18.6	0.915
Aug. 30	0.519	−1.7	18.0	0.907
Sept. 3	0.538	−1.6	17.3	0.899
Sept. 7	0.558	−1.5	16.7	0.892
Sept. 11	0.578	−1.4	16.8	0.886
Sept. 15	0.599	−1.3	15.6	0.880
Sept. 19	0.620	−1.2	15.0	0.875



Distances are given in astronomical units. To convert to kilometers, multiply by 149,600,000. Diameters are in seconds of arc. The phase is the fraction of the Martian apparent disk that is illuminated. On July 10, the day of opposition, Mars is totally illuminated.

Most of the dust seems to originate from the Serpentis-Noachis-Hellas regions. Billowing dust clouds can either veil localized surface features, so that their definition is slightly reduced, or completely envelop the globe, turning the planet into a featureless, dull-yellow ball. This happened during oppositions in 1956 and 1971. Dust storms spread rapidly and can take weeks or even months to clear. The yellow dust clouds lie very close to the surface and usually are not carried very high into the tenuous atmosphere. A yellow or green filter will increase the definition of these clouds as well as enhance surface features that may be partially obscured.

More elusive are the blue-white and white clouds. These appear in the southern hemisphere in early Martian spring when the polar cap is shrinking. Most sightings seem to be confined to the southern mid-temperate and equatorial latitudes, −35° to 30°, — although their predominance here may be due to the fact that we can better observe the southern hemisphere from Earth during perihelic opposition. They are most visible near the limb of the planet, they cover a much smaller area than the yellow dust clouds, and they are more limited in duration as well.

Surface Features

In small telescopes the most visible features on Mars are the maria, or seas. Like lunar maria, the Martian versions are vast dark plains, either flooded with lava or, like the Hellas basin, filled with drifting dust and consequently not as dark. Typically, as Martian spring turns to summer, the maria darken on a wave from pole to equator. Astronomers attribute this effect to the decreased reflectivity of the Martian surface as its atmospheric density increases with polar defrosting.

One of the most obvious features visible in small telescopes is the triangle-shaped Syrtis Major. This ridged plain slopes northeast, funneling down like an hourglass to the edge of Utopia Planitia, a featureless plain in the eastern mid-northern latitudes. Syrtis Major, like all Martian features, varies in shape because of the strong winds that stir up dust, alternately covering or exposing the dark underlying surface.

Other prominent equatorial features (moving progressively westward from Syrtis Major) include Sinus Sabaeus and Sinus Meridiani, Margaritifer Sinus, and Mare Erythraeum. Sinus Sabaeus, located southwest of Syrtis Major, is an elongated feature oriented east to west. Sinus Meridiani, the rounded nodule-like feature at the western-most extension of Sinus Sabaeus, lies on the Martian zero longitude. During periods of good seeing, those with telescopes of moderate aperture may notice two stubby extensions pointing northward from this feature. The Margaritifer Sinus is another dark feature similar in shape to Syrtis Major but much smaller. Mare Erythraeum, including the dark Aurorae Sinus, is a mottled, amorphous plain 10° southwest.

West-southwest is Solis Lacus, a small, comma-shaped feature that is difficult to find in a small telescope except when it stands out well against the lighter surroundings of Solis Planum. Farther west and south is Mare Sirenium, which is lighter in shade than Solis Lacus and hook-shaped.

Continuing westward, we next encounter Mare Cimmerium and the darker Mare Tyrrhenum, both located on the Hesperia Planum, which is southeast of Syrtis Major. The Hesperia is a vast, mottled plain dominating the eastern region of the planet south of the equator.

Hellas and Argyre are the two bright "spots" in the southern hemisphere. Argyre is located about 50° south of Sinus Aurorae, and Hellas, the larger of the two, is centered at roughly 45° south latitude — directly south of Syrtis Major. Both are basins, not plateaus as once believed. Hellas, in fact, is the deepest depression on Mars. When filled with dust both basins can appear very bright. Hellas, in particular, is quite variable in brightness and during peaks can rival the polar cap.

Although the southern hemisphere is better placed for observing, don't neglect the northern hemisphere. Mare Acidalium might be visible in the northern mid-temperate zone as a large, shaded patch extending toward the limb of the planet.

Mars is a planet filled with observing possibilities. The mutability of the planet's surface features and clouds make it a fascinating study for novice observers with small telescopes. But Mars also affords the opportunity for more dedicated observers to contribute to planetary science. Systematically monitoring the planet for cloud formations, dust storms, the size and shape of the maria, and the appearance of "new" features can help fill in the gaps in our knowledge of Mars.

At least one organization, the Association of Lunar and Planetary Observers, compiles and reduces data gathered by amateur astronomers. For more information on conducting Mars patrols and submitting observations, write to Charles Capen, Mars Recorder, Association of Lunar and Planetary Observers, Solis Lacus Observatory, Rt. 2, Box 262-E, Cuba, MO 65354.

For those who have never observed Mars, now is the time to study the Red Planet in a telescope and watch it grow and change. Luckily, you will have another good opportunity in 1988. After that, the next perihelic opposition won't occur until 2003.

— *Jeff Kanipe*

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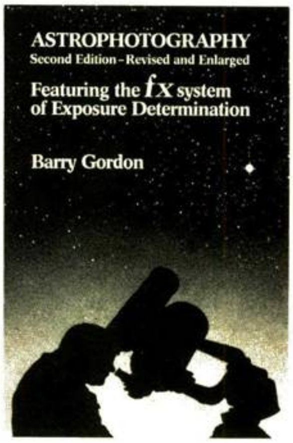
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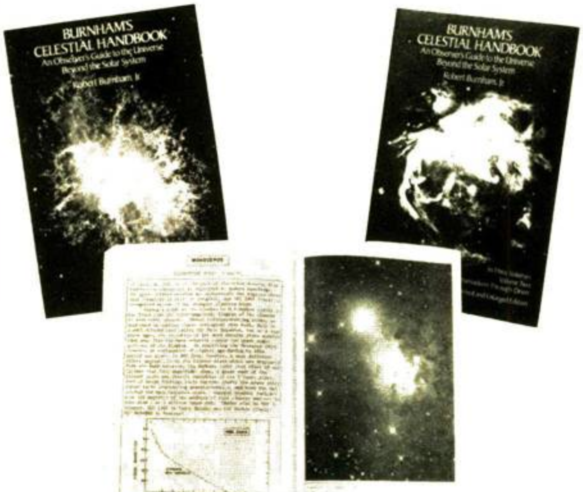
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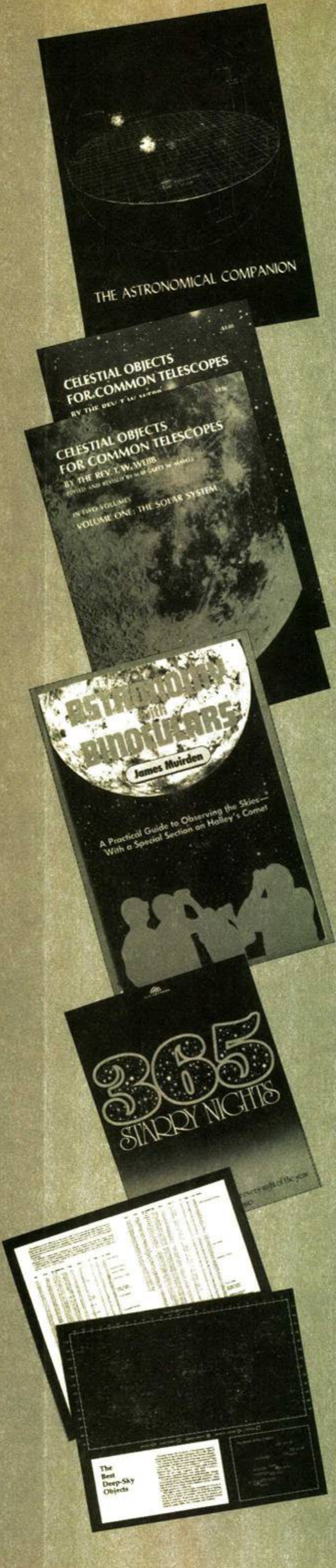
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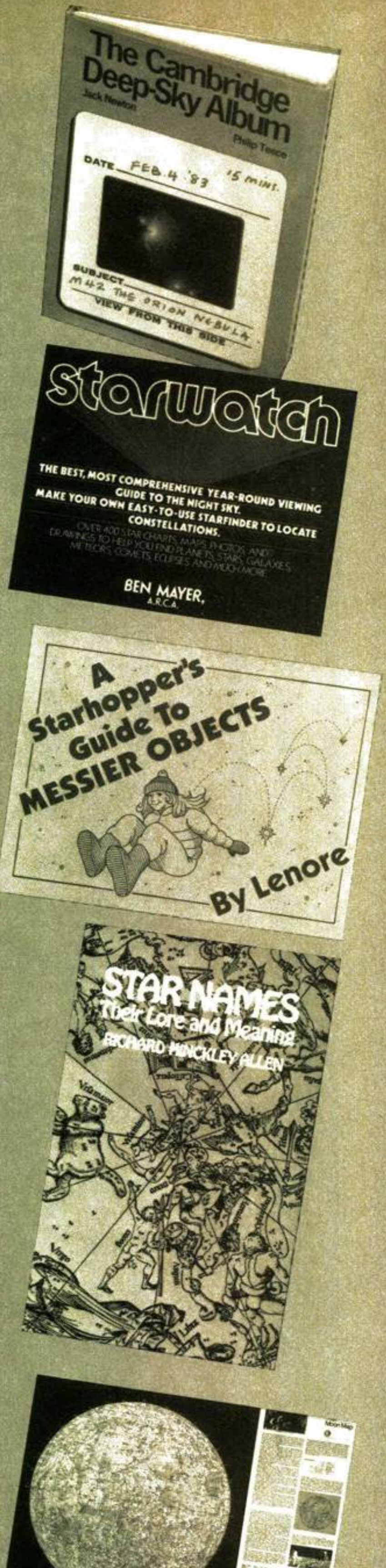
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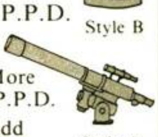

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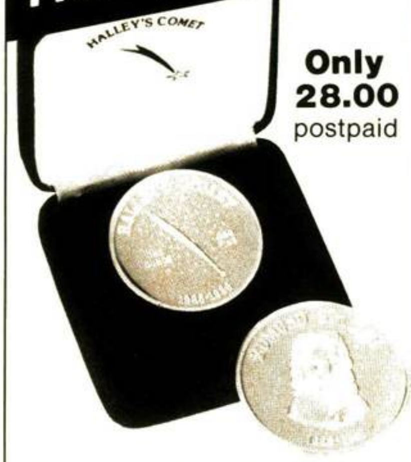

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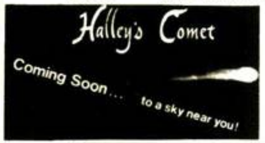
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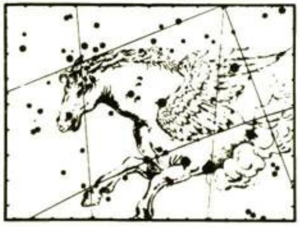

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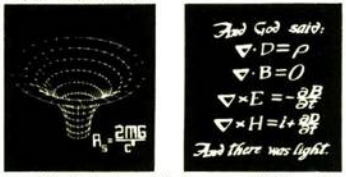
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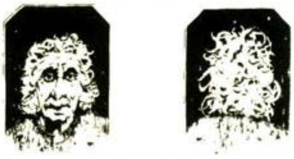

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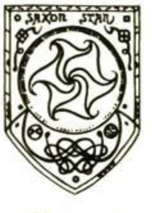

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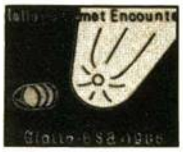

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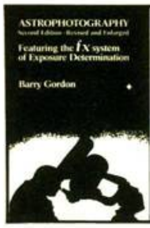
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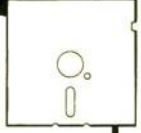

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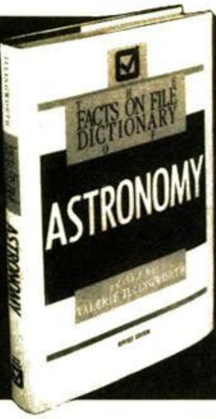

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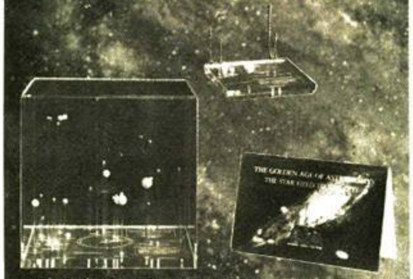

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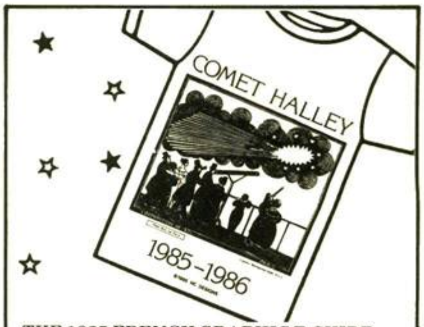

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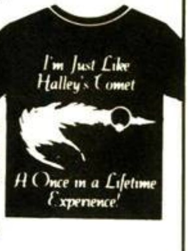

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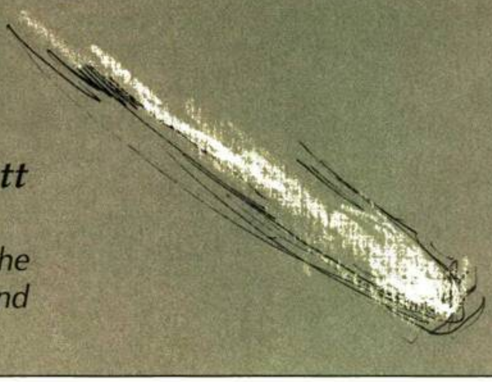
Intensely Seeking Halley



by Stephen Cole and Richard Talcott

Astronomers around the world are observing the comet in an unprecedented effort to understand this famous visitor.

Comet Halley is a small, dark body beyond the range of human vision during most of its orbit around the Sun. When it becomes visible, it is little more than a tiny grain of light embedded in darkness. As it finally brightens and takes on its own distinct shape for a few months, the comet's essential self — the nucleus — is hidden in a bright glow of light.

On this trip around the Sun, Halley's lighted path has been followed by human eyes with unprecedented intensity and determination in an effort to extract the secrets that darkness, light, and distance have withheld. By the time the comet fades into darkness, amateur and professional astronomers will have compiled a massive archive of data on Halley that will contain more information than all previous comet data combined. The sky's most popular comet will soon become the centerpiece of cometary science.

Being one of the brighter comets, one with a well established orbit, a wide range of cometary characteristics, and a generations-old legacy of popular appeal, Comet Halley has attracted a worldwide observational effort that has been coordinated by the International Halley Watch. Working through a network of "discipline specialists," each concentrating on one of the major observational techniques used to study comets, the IHW collects observations and facilitates communication between observers.

This unprecedented observational effort has utilized every established research technique known to cometary science, as well as some that are new to the field, to extract the information hidden in Halley's faint light. By watching how the comet moves along its orbit, how its tails transform as they stream away from the coma, and how the comet brightens and fades, astronomers hope to gain a thorough understanding of this small, infrequent visitor.

Watching Halley Move

Plotting a comet's motion against the stars is one of the oldest methods of understanding the nature of comets. This technique, called astrometry, is used to establish the orbits of comets. Donald Yeomans, one of the IHW discipline specialists, is coordinating the collection and analysis of astrometric data at the Jet Propulsion Laboratory in Pasadena, California.

Observatories in forty-seven countries are providing Yeomans with precise positions of the comet. "What observers do," says Yeomans, "is to take wide-field photographs of the comet against the star background. The trick is to get as short an exposure as possible that still has six or seven background stars on the plate. You want just a little speck of the comet on the plate since you don't want to measure the center of mass from an enormous coma. We never do measure the actual position of the nucleus because we never see it. We measure the center of light — the central brightness peak — and assume that is the location of the nucleus."

Post-perihelion observations of Halley showed that as the comet became very active, its central brightness peak apparently shifted sunward of the actual center of mass. An estimated value had to be used to correct this shift.

"Observers then measure the distance in millimeters between each star and the comet's center of light," explains Yeomans. "With a knowledge of the plate scale, you do a solution that determines the position of the comet given the known position of the stars."

Yeomans has been surprised by the unexpected dedication of many of the observers providing positions. "Recently, a good number of our observers have actually been taking images in the early morning sky, staying up to reduce their data, and phoning it in before they go to bed. Astrometry is not used to working like this. These really are heroic efforts."

Specially prepared star catalogues showing Halley's orbit were given to observers to improve the accuracy of their observations — another unusual effort in this type of work. "We had a whole survey done for the southern skies, which are not well mapped," Yeomans explains. "The U.S. Naval Observatory generated a special Halley catalogue covering about a degree-and-a-half on either side of the comet's path." This catalogue was later updated to cover the comet's path between January and mid-March.

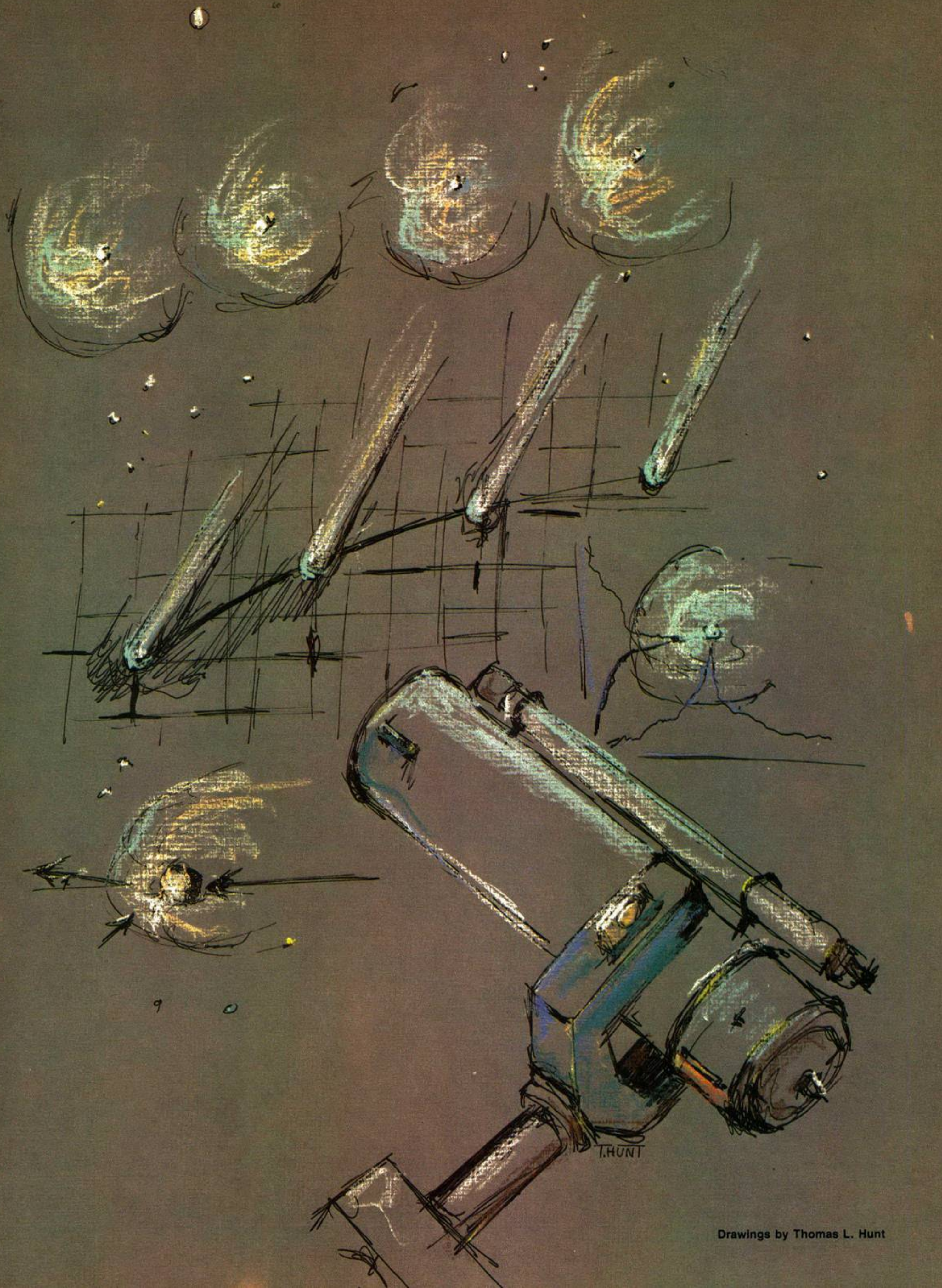
This type of preparation is the key to obtaining high-quality data, according to Yeomans. "The IHW went out of its way to make sure that people were using the same type of filters and data reduction techniques so that the data from several different observatories could be compared, which has not been the case in the past. It's really the coordination that makes this such a powerful project."

Astrometric data also yields insights into other questions about comets. Careful analysis of successive comet orbits have shown there are factors influencing these orbits that cannot be explained by the gravitational influences of other solar system bodies. These "nongravitational effects" originate from the comets themselves.

"We have a model on the computer that takes into account all the gravitational effects of the Sun and planets," says Yeomans. "But that's not enough to explain the astrometric observations of Halley taken over three or four centuries. You have to introduce small rocket-like thrusts."

"Comets outgas preferentially toward the Sun and introduce a rocket-like thrust away from it. We try to model these effects, and we keep adjusting our model until we best fit the data from, for example, 1607 to the present day. If the model isn't doing a good job of predicting the data we get, then we have a problem with our model."

Modeling of these nongravitational effects has also enabled astronomers to study the composition of the comet. "Our work was one of the first to point out that these rocket-like effects are due primarily to water-ice outgassing, not anything more volatile or less volatile than water ice," says Yeomans. "That was the



Drawings by Thomas L. Hunt

ice that was most consistent with the orbital work we had been doing. So we do shed some light on the physics of the comet as well as providing predictions of where the comet is."

A completely new use for astrometric data has been guiding spacecraft to the near encounters with Comet Halley that took place in March. The Soviet space agency Intercosmos agreed to provide the European Space Agency with data from Vega 1 and 2 that would be used to guide ESA's Giotto mission to the comet. This effort, called Pathfinder, also utilized NASA's Deep Space Network.

"The Soviets have provided a great deal of astrometric data because of their interest in the Vega missions," Yeomans reports. "We determine the comet's position from ground-based astrometric data to within a couple of hundred kilometers in space. Giotto, of course, wants to fly by with an accuracy of 50 kilometers.

"The Deep Space Network tracks the Vega spacecraft and determines where it is with an accuracy of about 50 kilometers. That gives the geocentric distance of Vega. Vega then observes the comet with its cameras and gives positions of where the comet is relative to the spacecraft. You now have a vector from the Earth to Vega and Vega to the comet and that allows you to complete the triangle and update the position of the comet to within 50 kilometers."

Variations in the Tail Structure

Observations of the structural details of comet tails, nuclear jets, and comae were recorded with pencil and paper before the advent of photography in the 19th century. Modern-day observers are collecting essentially the same type of information but with techniques that greatly enhance what they are able to see.

Wide-field photography is the data collection technique used by observers participating in the IHW's large-scale phenomena network. "In a sense, we're using the most old-fashioned methods of any of the IHW nets," says Malcolm Niedner, Jr., IHW discipline specialist and an astrophysicist at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

"Basically, our method is wide-field photography on glass plates and film. The state-of-the-art part of our research is the advanced image processing techniques we use at Goddard." Contrast enhancement and masking techniques are used to pull out fine detail in the comet's tail.

Large-scale phenomena include the comet's dust and plasma tails. "Here at Goddard," says Niedner, "we are primarily interested in the plasma tails. They vary in structure so rapidly, with major variations in hours or half hours. The dust tail, in contrast, tends to stay stable for days or even weeks.

"What our network observers are doing, at slightly over one hundred sites," explains Niedner, "is getting Schmidt camera telescope time, taking the glass plates or films, developing them, and sending them to us. Then we micro-densitometer the images to get the best information from them." NASA/Goddard is where this image processing is done for the IHW net.

"You need a very complete network around the world to be able to follow all the changes in the tail," according to Niedner. To this end, additional observers were recruited to fill in the gaps in coverage. The "Island Network" consists of observers stationed on Easter Island, Reunion Island in the Indian Ocean, Tahiti, South Africa, and British Antarctica.

"Because our science goals are so strongly coupled with coverage," says Niedner, "we've been very concerned about covering the comet in the southern skies. So what we've done is to send volunteers with 8-inch Schmidt cameras into the Southern Hemisphere. We've incorporated the help of volunteer observers, some of whom are professionals, some of whom are advanced amateurs. They're going to try to fill in the gap we have in continental land-based sites." Island Network observers were photographing the comet from March to May.

The coverage problem seems to have been resolved, however. "We have gotten more observers around the world excited about photographing the comet to detect rapid changes than we ever have before," says Niedner. "Not even the bright comets of the past such as West and Bennett stimulated this density of coverage."

The data collected from these efforts will help to solve continuing debates on the nature of the interaction between comets and the solar wind. Although large-scale cometary structures have been studied for some time and theories about the mechanisms causing them have circulated since the beginning of the century, astronomers have only recently begun to understand how these mechanisms work.

In 1951, the year following both the announcement of Fred Whipple's "dirty-snowball" theory and the Oort Cloud theory of cometary origin, Ludwig F. Biermann theorized that the acceleration of knots in comet plasma tails was caused by the then new concept of the solar wind, a continuous outflow of ionized material from the solar corona. "Since then, cometary plasma tails have been studied in the context of solar wind interaction, but only in broad brush," says Neidner. "Most of the details are still very complex."

It is from the activity of comets that astrophysicists like Niedner have learned about the properties of the solar wind. "Comets are natural probes, and they are free. You don't have to spend millions for a spacecraft."

One cometary event that will shed light on the nature of the solar wind is a disconnection of the plasma tail from the head of the comet. Ions from the outer regions of the comet's atmosphere are deposited into the solar wind where they are captured on the wind's magnetic lines of force. The solar wind's magnetic field interacts with the magnetic field of the comet's tail to cause the disconnection events.

According to a model developed by Niedner and his colleague, John Brandt, a comet loses its tail when it crosses a new sector boundary in the solar wind that contains a magnetic field opposite to the field from which the tail developed.

Disconnection events are fairly frequent occurrences and several have been observed in Comet Halley. "What was once thought in the late 1960s to be a very unusual event is now seen to be very commonplace. I've looked at photographs taken over the last ninety years of thirty different comets and I see these disconnection events time after time," says Niedner.

"What we try to do is determine the time of the disturbance. If we have many photographs showing a disconnected tail, showing the motion, we extrapolate that tail back to when it was just connected to the head. That determines the disturbance time. Presumably something in the solar wind arrived at the comet at that time.

"Then we get our hands on all the interplanetary data we can, either from satellites in orbit around the Earth or interplanetary spacecraft like the International Cometary Explorer. ICE was directly upstream from Halley in March — a perfect position to monitor the solar wind," says Niedner. Using accepted methods of mapping the solar wind from the location where it is directly observed to the comet, accurate time correlations can be made between the solar wind and the disconnection events.

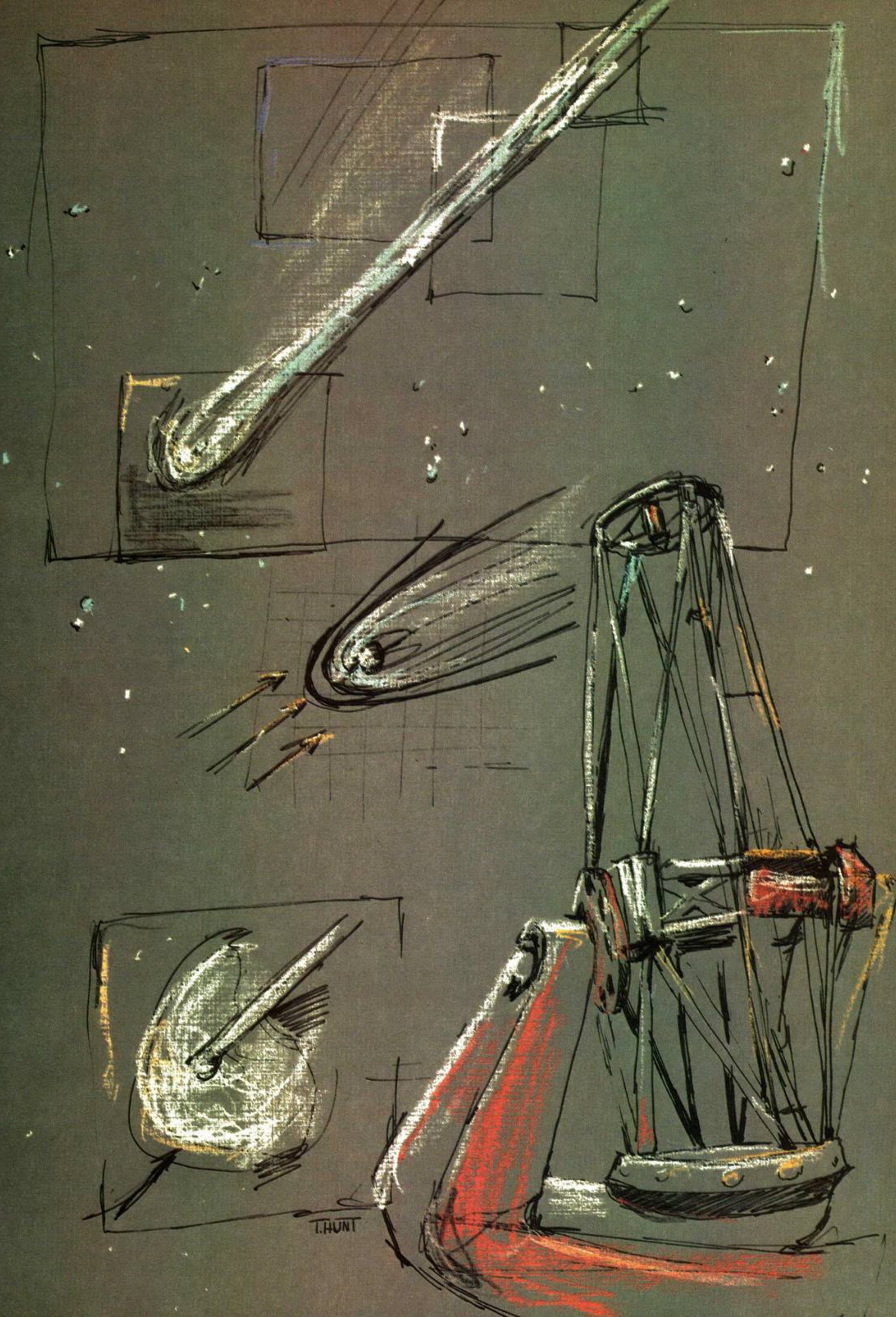
Closing In on the Nucleus

By getting a close look at the area near the nucleus of Halley, including the dust jets that periodically flare from its surface, astronomers hope to determine the comet's rotation rate and even map its surface.

David H. Levy of the IHW near-nucleus studies net is working with Stephen Larson at the University of Arizona's Lunar and Planetary Lab in Tucson. "Our aim is to get as close in as we can," says Levy. "With a long focal-length telescope, like the 61-inch instrument here on Mount Lemmon, we're able to get really tight in to the nucleus and get nice pictures of jets. We use a charge-coupled device, or CCD, with various filters. The most important filter is the red filter. We seem to get better jets in red than we do with any other filters."

Observers send photographs, CCD images, and sometimes even sketches to the IHW near-nucleus center at the University of Arizona.

"Our goal is to get a series of images in red over successive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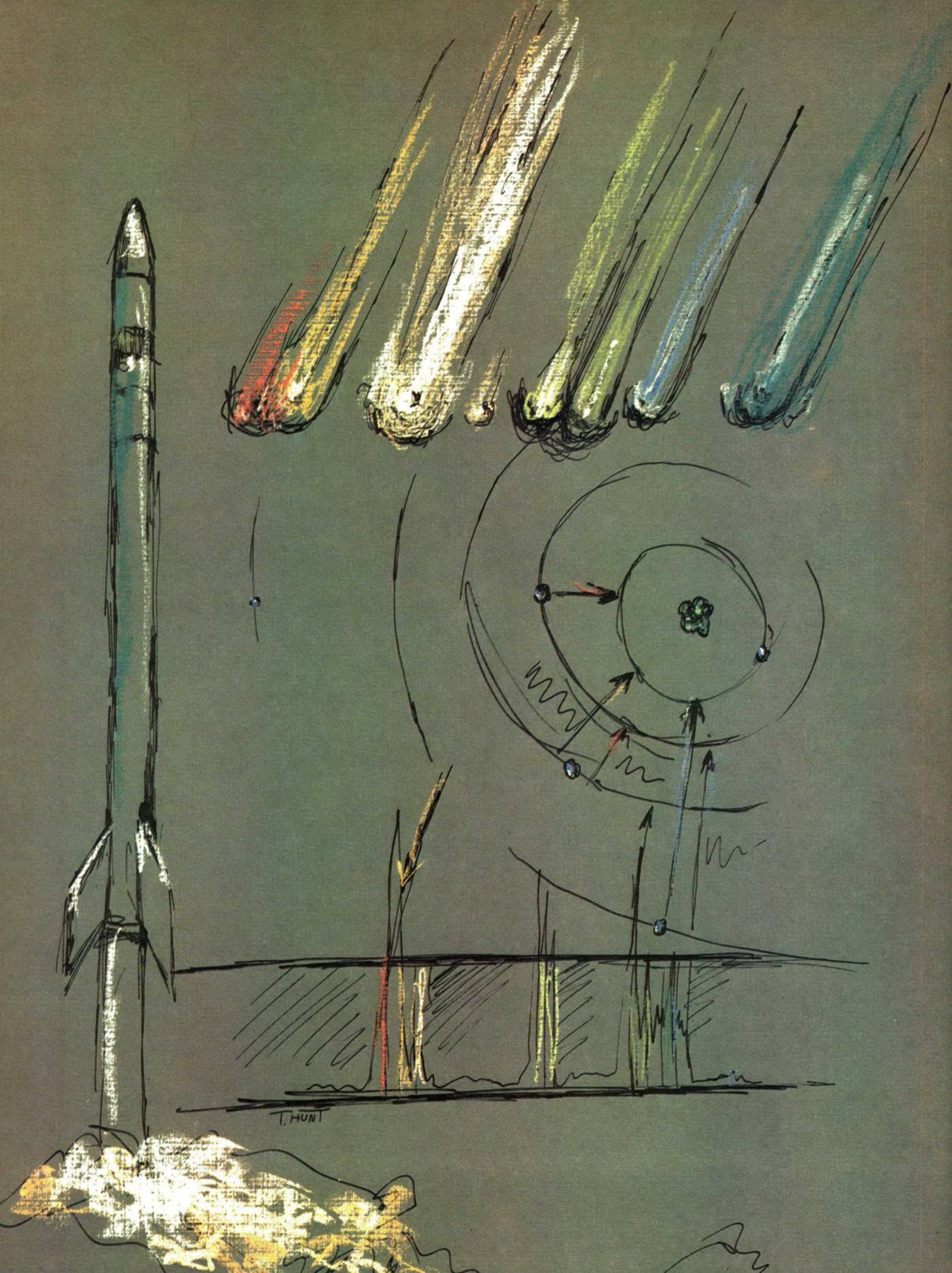
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nights to show behavior of the jets. Of the 78 possible nights last fall that we could image Halley, we got good images on 67 of those nights. That's really what it's all about: getting consistent coverage night after night," says Levy.

Levy is not yet certain how complete that coverage is, since few images have arrived so far. "I just sent a newsletter out to all the members of the net, about 300 of them," said Levy last March, "in which I asked for observing logs, if not images, so that we know what we've got."

Once the images are received, they are processed to enhance the structures around the nucleus. Then, Levy explains, "We measure the jets to find out their length in arcseconds, their curvature, and their positions relative to the brightest part of the comet, which would seem to be the nucleus. The final stage is to actually model them with computer programs to figure out exactly where on the nucleus the jets are coming from."

The jets can be used to determine the rotation period of the comet. "We want to get as many images of jets as possible to figure out the rotation period," Levy says. "If a jet is strong enough that it appears and disappears as the nucleus rotates and it is still active when it comes around again, then the jet can be used to assume that this is an effect of rotation."

The first tailward jets detected by Levy and Larson were seen on January 6. "The tailward jet is the most important type of jet. These jets are very linear, almost like a thread."

An estimated rotation period of 52 hours for Halley was established by Larson and Zdenek Sekanina of the Jet Propulsion Laboratory from the jet activity on photographs made during its 1910 apparition. (See "Mining Old Silver," October 1985). The photographs were digitized and carefully processed so that the jets could be seen and measured.

The jets also indicate what the surface of the comet looks like. They erupt through fissures on the surface of the comet that are similar to volcanic fissures on Earth. "The more jets we see and are able to map," says Levy, "the better idea we'll have of what the nucleus looks like." A preliminary map of these fissures on the nucleus has been produced by Sekanina using the 1910 Halley data.

The relative inferiority of Halley's current apparition compared to that of 1910 has not been a hindrance to near-nucleus observers. "Although the 1910 apparition was better than the current one, we were able to get better data from the CCD system, unprocessed, in January before the comet got close to us than they got in 1910," says Levy.

The data collected on jets was supplied to the Giotto mission scientists so that the spacecraft could avoid major dust jets in its encounter with the comet. The near-nucleus data will also be correlated with the astrometric data to help explain the nongravitational effects. "We know that jets effect the orbit of the comet," says Levy. "We want to study them as soon as they start, as far out as they go. We really want to know every last one of them, how strong they are, where they are, and the directions they come from."

The Mount Lemmon research is expected to wrap up in June when the comet gets too close to the Sun in the evening sky and the jet activity decreases. The main CCD system, which was shipped to South Africa in January, will continue collecting images until then.

As Halley Brightens and Fades

Aside from the obvious motion of comets and their distinct physical characteristics, their most noticeable feature is variation in brightness. This is not merely an effect of the comet's changing proximity to Earth. It is, more importantly, a direct indication of activity on the nucleus and in the surrounding coma. By measuring Halley's variations in brightness, astronomers hope to determine its rotation rate, composition, and the amount of gas and dust streaming off the nucleus.

Michael A'Hearn, professor of astronomy and acting director of the astronomy program at the University of Maryland, College Park, is the IHW discipline specialist for photometric studies. A'Hearn has been monitoring the comet from Australia with the Perth Observatory's 24-inch planetary patrol telescope. He has also been involved with the ultraviolet investigation of the comet being conducted with the International Ultraviolet Explorer.

"Photoelectric photometry of comets has existed for roughly thirty years," says A'Hearn. Photometric observations have evolved from visual estimates of brightness to the precise counting of photons of light by photoelectric photometers. This equipment amplifies the comet's faint light into a measurable electrical current.The only extensive body of photometric data on comets, however, has been compiled in just the last ten years by A'Hearn and Robert Millis of Lowell Observatory.

The first light we see from the comet is reflected sunlight from the nucleus. At a certain distance from the Sun, the nucleus then "turns on" and the comet begins to generate its own light as the gas molecules in the coma break up. Sunlight reflected by dust particles in the coma also contributes to the total brightness of the comet.

Plotting the change in total magnitude as a function of distance from the Sun yields a characteristic light curve for a comet. The light curve of Comet Halley shows a sudden brightening at 6 astronomical units, a distance slightly farther from the Sun than Jupiter. This finding indirectly confirms that Halley's nucleus is essentially composed of water-ice, which would start to sublimate at the temperature found that far from the Sun.

"We have gotten more observers around the world excited about photographing this comet than we ever have before."

— Malcolm Niedner,
NASA/Goddard Space Flight Center

A light curve can also serve to confirm — or refute — other factors that influence the brightness of the comet, such as its rotation rate and the production rate of gas and dust. Using predicted quantities for these different factors, astronomers can produce a model light curve of the comet. If the model curve matches the actual light curve, the predicted quantities are confirmed; if the curves do not match, the model must be changed.

More direct photometric evidence of cometary composition is obtained by using filters to focus in on a certain portion of the total range of light. In this way astronomers can separate the light reflected by dust particles from that produced by different gases in the coma. The varying brightness of these different bands of light indicates the rate at which gas and dust is produced in the coma. From these data, inferences can be made about the vaporization properties of the nuclear ices.

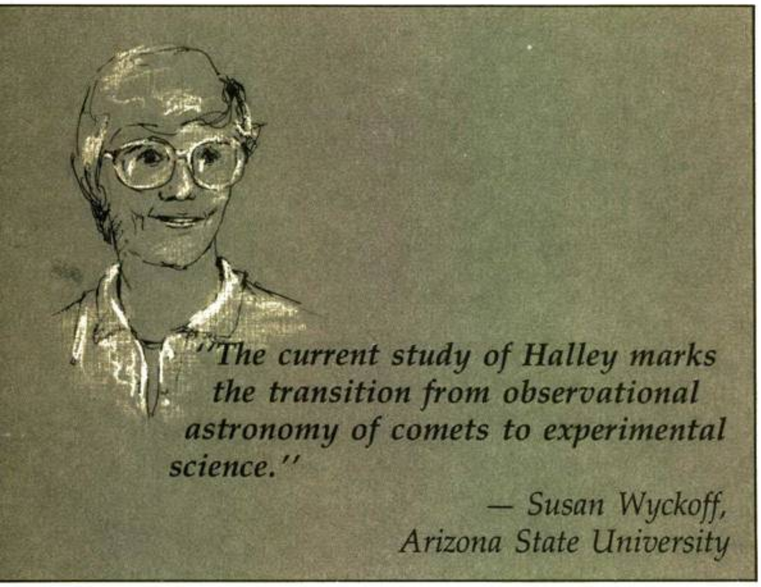
"Basically, we estimate the rate at which different molecular species are produced by the nucleus and the rate at which dust is produced by the nucleus and how that changes with time," says A'Hearn.

Breaking Down the Comet's Light

Another way of breaking down the light from a comet is to pass it through a spectrometer, which spreads the light out into individual wavelengths. Intense readings at certain wavelengths and weak readings at other wavelengths form a unique spectral signature that is a direct indication of the chemical composition of the gas producing the light. Astronomers attempt to match the spectra produced by the comet with the known spectra produced by different chemical compounds.

Susan Wyckoff and Peter Wehinger of Arizona State University in Tempe are the IHW discipline specialists for spectroscopic studies. "We have been monitoring the spectral evolution of the comet from 11 AU to perihelion and out again to where it can no longer be picked up," says Wyckoff. They have been observing at Kitt Peak, the Multiple-Mirror Telescope Observatory in Arizona, and Cerro Tololo Inter-American Observatory in Chile.

"For the first time," says Wyckoff, "we have actually monitored the nucleus of the comet and its turn-on and detected the onset of sublimation in the comet." Spectroscopic studies of the gas tail have shown that it consists of ionized molecules, primarily carbon monoxide ions. By determining the chemical composition of the tail and coma, astronomers hope to derive the composition of the parent molecules in the nucleus.



> *"The current study of Halley marks the transition from observational astronomy of comets to experimental science."*
>
> *— Susan Wyckoff, Arizona State University*

Based on pre-perihelion observations, Halley has exhibited a unique spectrum. "I would characterize the spectrum of Comet Halley as distinct from others in that it has a very strong NH_2 spectrum — the ammonia radical," says Wyckoff. This spectrum may change, she expects, with post-perihelion data. "Comparing pre- and post-perihelion data will be interesting because we'll be looking at layers of the surface of the comet that are several meters deeper in the nucleus. These are layers from which CO and other very volatile ices may not have diffused. We may find a different CO-to-H_2O ratio in the coma after perihelion."

Arizona State is the IHW spectroscopy net center. Wyckoff has received many calls from astronomers who are not involved with the study of Halley but who want to offer their services to the observational effort. "People have called us asking, 'We have this instrument that we usually observe galaxies with and we have a little bit of time to get some CCD images. What can we do with the comet?' " Wyckoff then recommends specific observations that will fill a need in the overall observing program.

Spectroscopic studies in the ultraviolet — light with wavelengths just shorter than visible light — reveal a different set of compositional features that are not apparent in the visible range of the spectrum. Ultraviolet observations have shown an overwhelming dominance of hydrogen atoms and hydroxyl molecules in cometary spectra, which is a strong indication that water is one of the parent molecules.

Because ultraviolet radiation is absorbed by Earth's atmosphere, UV measurements cannot be taken from the ground. The International Ultraviolet Explorer satellite, which has been in orbit since 1978, has been used to observe many comets at ultraviolet wavelengths. An intensive cycle of Halley observations began in September 1985 and continued through April 1986. The IUE detected a very high outgassing rate, compared to that of other comets, and a significant, rather compact dust coma measuring 20,000 kilometers across. The observations have been conducted by Paul Feldman of Johns Hopkins University and Michael A'Hearn.

Ultraviolet observations have also been taken with sounding rockets launched from White Sands Missile Range in New Mexico last February and March by the Naval Research Laboratory. The rockets, carrying two far-ultraviolet Schmidt cameras, flew to an altitude of 190 miles and observed the comet for five minutes. They returned images of a huge hydrogen cloud extending more than 8 million kilometers from the nucleus.

The science team on these experiments included Chet Opal of the University of Texas at Austin, and Robert McCoy, George Carruthers, and Robert Meier of the Naval Research Lab. Opal was a member of the Astro Halley Science team that had planned to make ultraviolet observations from the Space Shuttle at the time of the spacecraft encounters with Halley. The March sounding rocket launch was scheduled to make up for the cancellation of the Astro Halley Shuttle mission.

Light from Ice, Water, and Dust

Examining light with wavelengths just longer than visible light — in the infrared part of the spectrum — reveals details about the composition and size of the dust flowing off the comet; it has also provided the first evidence of ice grains on the nucleus and water vapor in the inner coma.

Roger Knacke of the State University of New York at Stony Brook is the IHW discipline specialist for infrared spectroscopy. Knacke came to the current study of Comet Halley with a background in interstellar material. "I was interested in the solid material between the stars and the possible connection between that material and comet dust," says Knacke. "Perhaps the comet material is formed in the same way as interstellar dust, or perhaps comets contain interstellar dust that they bring into the inner solar system. We don't know yet exactly what the connection is."

Observations of previous comets have detected the emission features of silicate grains in infrared spectra. By measuring the intensity of the continuous emission in the spectra — the part of the spectrum produced by reflected sunlight from comet dust — astronomers have also calculated the temperature of the dust grains.

Knacke, who has been doing infrared spectroscopy of Halley at the Infrared Telescope Facility in Mauna Kea, Hawaii, and at Kitt Peak, has also been measuring the infrared polarization of the light from the comet, a technique that is relatively new to the study of comets. The first comet to be studied in this way was Comet West in 1976.

"What we measure," says Knacke, "is the scattered light from the dust particles. Aside from putting their own spectral signature on the light from Comet Halley, the dust particles scatter the light toward us and polarize it."

The light that leaves the Sun is randomly polarized, meaning that the electromagnetic waves making up the light are not aligned in any particular way. But when that light strikes a surface, such as a comet, some of the light is absorbed and the reflected light no longer has a random polarization. Measuring the particular polarization of the light is an indicator of the size and structure of the dust grains that scatter it.

Over the past two years Knacke has been doing some modeling of the many complex factors that influence the polarization of light from comets. Later this summer, when all the infrared spectroscopy and polarization data are in on Comet Halley, Knacke hopes to begin constructing new models of the dust grains. It should be a busy summer.

"We're going to get far more infrared data on Comet Halley than we have on all previous comets," says Knacke.

Infrared observations conducted on Halley have also produced the first-ever detections of ice grains and water vapor in a comet. Last November, researchers from the University of California, Santa Cruz and NASA's Ames Research Center detected the characteristic infrared signature of ice grains using the 120-inch telescope at Lick Observatory.

The detection of water vapor was made last December by astronomers aboard the Kuiper Airborne Observatory (KAO) at an altitude of 41,000 feet. Since infrared radiation is partially absorbed by Earth's atmosphere, observations are frequently taken from airborne observatories. Using a new theoretical model of the infrared fluorescence spectrum emitted by gaseous water, which was developed by Michael Mumma of Goddard Space Flight Center and Harold Weaver of Johns Hopkins University, the observations detected the spectral lines predicted by the model.

Previous attempts to observe water at ultraviolet and radio wavelengths over the last twenty years have not been successful. "These attempts largely have failed because water does not fluoresce in the ultraviolet, and the new theory shows that water's radio spectral lines are too weak to be seen," said Weaver.

In March the KAO and seven teams of scientists traveled to Christchurch, New Zealand, for additional observations of Halley that continued through mid-April.

Observing When the Sun Is Up

The final region of the spectrum being explored for insights on Comet Halley is the radio region. Radio emissions from the comet can be observed while the Sun is in the sky because the Sun does not emit a significant amount of radio radiation.

"We were able to observe the comet all through perihelion while the optical telescopes were, of course, shut down," says Peter Schloerb, professor of physics and astronomy at the University of Massachusetts in Amherst, and one of the IHW radio science discipline specialists. Schloerb has been observing at the National Radio Astronomy Observatory in Greenbank, West Virginia, and at the Five College Radio Astronomy Observatory in New Salem, Massachusetts.

Radio observations of Halley were targeted around a few specific time periods, such as closest approach in November and perihelion in February. Observers looked primarily for signs of hydroxyl molecules and hydrogen cyanide molecules. Hydroxyl is a breakdown product of water, and hydrogen cyanide is a parent molecule from which other gases originate.

Observations of these molecules have been sketchy during the fifteen years that comets have been studied at radio wavelengths. "It was a little difficult to know how much to advocate radio observations of Halley because it wasn't obvious that any one would see anything," said Schloerb. "I honestly didn't expect that we would see anything. But people really have been getting interesting data."

That data has shown that emissions of hydrogen cyanide vary in strength from day to day, apparently coinciding with bursts of dust from the nucleus. The failure to detect hydrogen cyanide in previous, less active comets, which resulted in Schloerb's doubt as to radio's role in cometary studies, can now be attributed to the apparent variability of this emission. "The fact that we see it now and that it's wildly time variable sure makes us feel better about some of the marginal detections we've had in the past."

Now that the variability of hydrogen cyanide is established, Schloerb has attempted to spread the news and find more observers to look for it. A special electronic bulletin board operated by the International Halley Watch was created as part of the IHW network to facilitate the exchange of this type of news between observers and IHW discipline specialists.

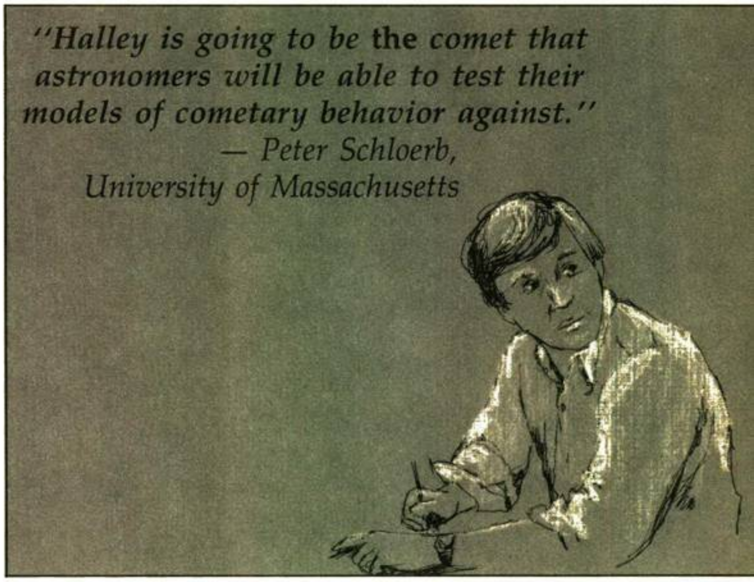
Headquartered at Arizona State University, the bulletin board is managed by Susan Wyckoff and Peter Wehinger. "The current status of the comet is posted daily on the bulletin board," says Wyckoff. "We also gather data from all the disciplines and put out messages on our electronic mail system."

Where To After Halley?

Once Halley disappears again and astronomers return from the Southern Hemisphere to begin analyzing their observations, cometary science will have quietly taken a quantum leap into the future. The accumulated astrometric, photographic, photometric, and spectroscopic data will form a body of cometary information without equal.

"This apparition of Halley's Comet will produce a ton of systematically taken observations using a variety of techniques to produce a thorough study of the behavior of comets," says Peter Schloerb. "Put that together with the spacecraft data and Halley becomes *the* comet that people will be able to test various models against to learn about the way comets are supposed to behave."

This compendium of information will certainly produce a much greater understanding of comets, but, as Susan Wyckoff warns, we should not assume that we understand all comets merely because we now understand Halley better. "The danger is that we're going to generalize what we learn in terms of other comets. But we cannot draw general conclusions until we have studied other comets in a similar way."



"Halley is going to be the *comet that astronomers will be able to test their models of cometary behavior against."*
— Peter Schloerb,
University of Massachusetts

The milestone that Halley marks, according to Wyckoff, is "the transition from observational astronomy of comets to experimental science and the planetary exploration of comets," which began with the Giotto and Vega encounters.

"We must pursue the study of comets with spacecraft," says Wyckoff. "The proposed Comet Rendezvous and Asteroid Flyby mission is a very proper follow-up to the current space missions in that it will follow a comet for months and months so that it can monitor the physical properties. It's a must if we are to understand comets."

The crossroad that cometary science has now reached is similar to the one reached in our understanding of Uranus earlier this year. In December 1985, our view of Uranus was based on decades of distant observations; one month later, a small spacecraft completely changed that view.

"You don't learn about the details of the composition of planetary atmospheres through planetary spectroscopy," says Peter Schloerb. "You learn about it by dropping a mass spectrometer into the atmosphere.

"To really understand why comets behave the way they do, you have to explain the nucleus of the comet," he adds. "Is the nucleus homogeneous or heterogeneous? What is it made of? Are the differences in activity from one place to another the result of some surface physical process or are they the result of some intrinsic factor that has been there since the formation of the comet itself?

"I think that the only way to get at these kinds of questions is to go out and get a closer look."

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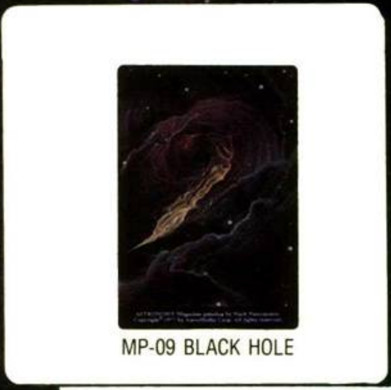

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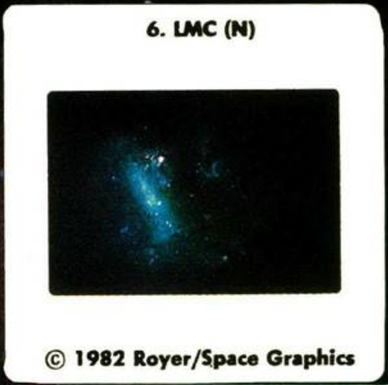

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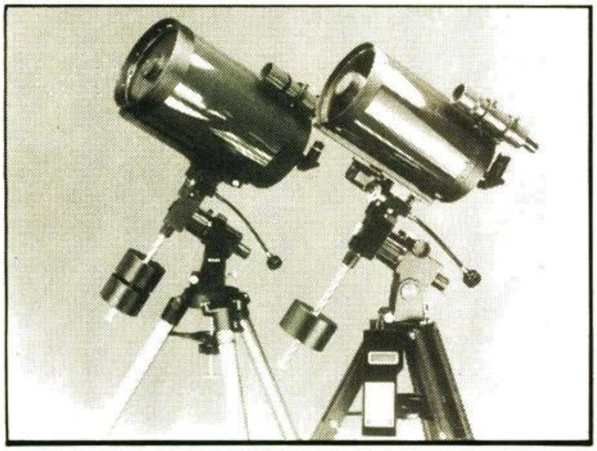

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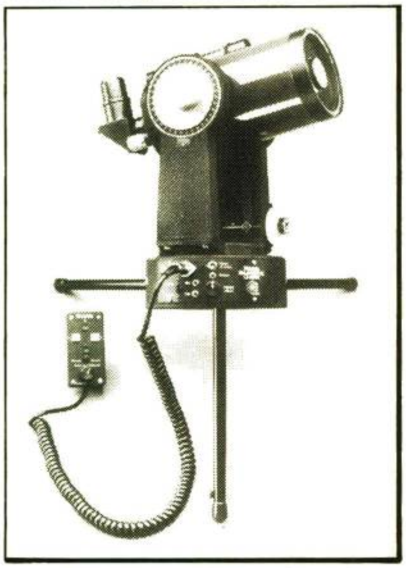

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1¼" 13.8mm Wide	$\$134^{50}$	2" 40mm Wide	$\$299^{50}$	1¼/2" 14mm Ultra	$\$264^{50}$

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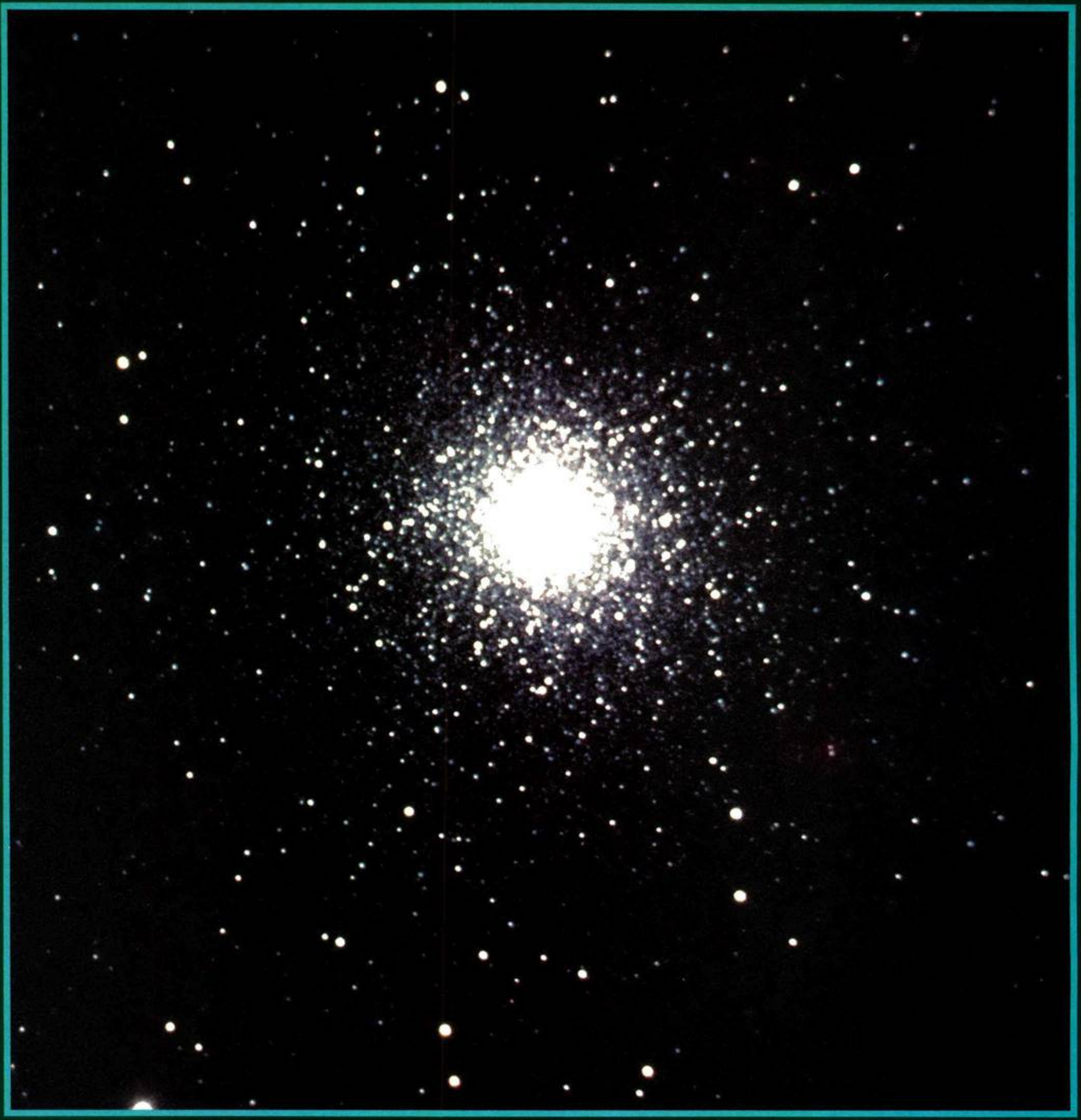
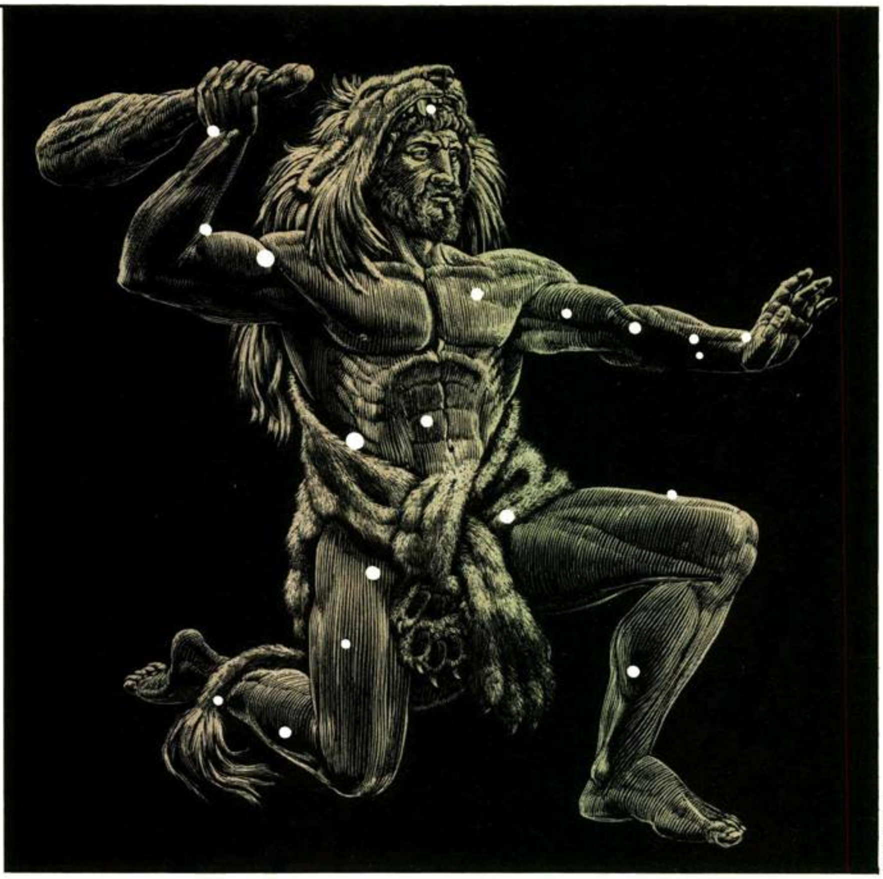


Above: M-13, the Hercules cluster, is one of the largest and brightest globular clusters in the sky. It is faintly visible to the naked eye under a dark sky, but its outer edges can be resolved into stars with telescopes as small as 4 inches in aperture. Photo by Bill Iburg. Far left: Overlooked because of its famous neighbor is M-92, also a fine globular cluster for small telescopes. Photo by Jack Newton. Left: NGC-6210, a tiny blue-green planetary nebula, requires high power for identification. Photo by Jack Newton.

Hercules

Her
Herculis


Keith Ward

Lying between the rich plane of the Galaxy in Cygnus and Lyra and the realm of faint galaxies in Bootes and Corona Borealis, **Hercules** the Strongman holds a mixture of easy globulars and faint galactic objects.

As constellations go, Hercules is large but rather faint. Its brightest stars shine at 3rd magnitude, making it traceable under dark skies but elusive where light pollution invades. The constellation's central asterism is the "Keystone," a trapezoid formed by Eta (η), Zeta (ζ), Epsilon (ε), and Pi (π) Herculis. It is recognizable even under typical suburban backyard conditions.

The constellation's best offerings are: M-13 and M-92, two of the best globulars in the sky; NGC-6210, a fine planetary nebula; and 95 Herculis, a double star showing one of the most striking examples of color contrast.

The appropriate starting point for deep-sky viewing in Hercules is **Messier 13** (NGC-6205), popularly known as the Hercules cluster. M-13 lies 2.5° due south of Eta Herculis, one of the Keystone stars, and is bright enough at magnitude 5.9 to spot with the naked eye under a perfectly black sky. Typically, however, it is visible only as a fuzzy "star"with finderscopes or binoculars.

You can find it most easily by starting at Eta Herculis (the northernmost star in the Keystone) and moving the telescope south about one-third of the way toward Zeta Herculis, the star at the small end of the Keystone. There you'll see the fuzzy disk of M-13, which forms a right triangle with two 7th-magnitude stars.

A 3-inch refractor shows M-13 as a uniformly lit disk of milky light some 8′ across; the view with a 4-inch refractor or 6-inch reflector is much better since the cluster's edges are resolved into faint stars. M-13 is a breathtaking sight in large backyard telescopes. A 10-inch or larger instrument and good seeing and transparency resolves stars across the entire face of M-13, showing hundreds of pinpoints against a velvety black backdrop of sky. On steady nights, don't be reluctant to use high power on the Hercules cluster. Its high surface brightness and remarkable number of component stars will reward you with a telescopic field jam-packed with tiny suns.

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

High powers may also produce two curious effects with M-13. First, notice that many of the cluster's outer stars seem to be arranged in long arcs, giving the appearance of appendages extending out from the cluster's center. Next, look at the distribution of stars across the cluster's face: there appear to be dark voids intermingled with patches of numerous stars, three of which meet in a Y-shape on the core's southeastern side. These are not "holes" in the cluster but rather perceptual effects of seeing more bright stars at one place and less at another.

M-13 is regarded by many Northern Hemisphere observers as the finest globular cluster, largely because it lies high in the sky from their vantage point. Actually, ten globular clusters are larger and six are brighter than M-13, although all of them are either invisible or low on the horizon for North American and European skywatchers. M-13's true diameter is some 37 parsecs and its distance is 7.7 kiloparsecs. It appears big and bright due to its close proximity, not because it is intrinsically large or luminous.

If you observe M-13 on a dark night and use a wide-field eyepiece, you may notice a tiny fuzzy patch of light in the same field, 1.5° north and slightly east of the great cluster's center. This is **NGC-6207**, a diminutive Sc-type spiral galaxy tilted about 45° to our line of sight. This little galaxy isn't terribly impressive in most backyard instruments (the only detail visible is a starlike nucleus surrounded by a misty envelope of light), but it does offer one of the sky's best examples of extreme depth of field. The galaxy lies 14.2 megaparsecs away — nearly 2,000 times more distant than its neighboring globular cluster.

Nearly 10° northeast of the M-13/NGC-6207 pair, in a relatively blank section of sky, is the fine globular cluster **M-92** (NGC-6341). This object is overshadowed by the popular Hercules cluster and would rate far higher on observing lists if it were located in another part of the sky. Shining at magnitude 6.5 and spanning some 11.2′ across, M-92 is nearly as large and bright as M-13, but since it is more compact it is harder to resolve into kindred stars. A 6-inch scope at high power will show a smattering of suns lining M-92's edges; a 12-inch instrument under ideally dark skies will essentially duplicate the view of M-13 in a smaller scope. M-92 is physically smaller and fainter than M-13 and lies slightly farther away.

A third bright globular in Hercules is **NGC-6229**, a magnitude 9.4 cluster located 7° northwest of M-92. A finderscope under a dark sky will show NGC-6229 as a tiny smudge of greenish gray light. Spotting it is easy because the cluster is located several arcminutes east of a bright, wide pair composed of 7th- and 8th-magnitude stars. NGC-6229 has a physical diameter about the same as M-92's; it is relatively faint and unimpressive only because it lies more than twice as far away as its brighter neighbors to the south.

Hercules contains three bright planetary nebulae observable in backyard telescopes. The best of the lot is **NGC-6210**, a bluish disk 14″ across, shining at photographic magnitude 9.3. (Since photographically derived magnitudes tend to run faint, NGC-6210 will appear as an 8th-magnitude object in your eyepiece.) To find this little planetary, start at Beta (β) Herculis, a 3rd-magnitude star located 10° south of the Keystone. Then move 4° northeast and you'll see a wide pair of 7th-magnitude stars, one of which is a double. NGC-6210 lies several arcminutes northwest of the single 7th-magnitude star.

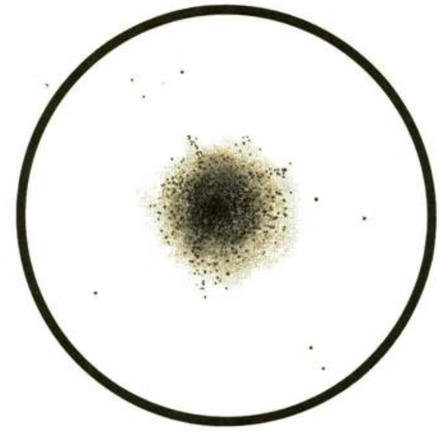
At first you may have trouble identifying this object due to its tiny size. Once you've found the right spot, switch to medium power and look for a bluish "star" that appears slightly out of focus — that will be the nebula.

The other two planetaries in Hercules are considerably fainter than NGC-6210 but still bright enough to see in small scopes. **NGC-6058** lies in a barren patch of sky near the Hercules-Corona Borealis border, some 8° northwest of M-13. It measures 23″ across and glows at photographic magnitude 13.3, causing it to appear as a pale ghostly patch of light. **IC 4593** shines at photographic magnitude 10.9 and is about the same size as NGC-6210. It lies in the constellation's southern end near the border with Serpens Caput.

Three unusual stars lie within Hercules' boundaries. Alpha (α) Herculis is a semi-regular variable with an approximate period of 90 days that witnesses a change in brightness of nearly one magnitude, between 3.1 and 3.9. Observe it throughout the summer and compare its brightness with that of the other 3rd- magnitude stars in Hercules. **DQ Herculis**, now a 15th-magnitude speck of light barely perceivable with amateur instruments, went nova in 1934 and shone at magnitude 1.3 for nearly two months. **95 Herculis**, a pretty double star consisting of twin 5th-magnitude suns, offers one of the most stunning color contrasts of any pair in the sky. The famed 19th-century observer Admiral Smyth described the colors as "apple green and cherry red." Do you agree?

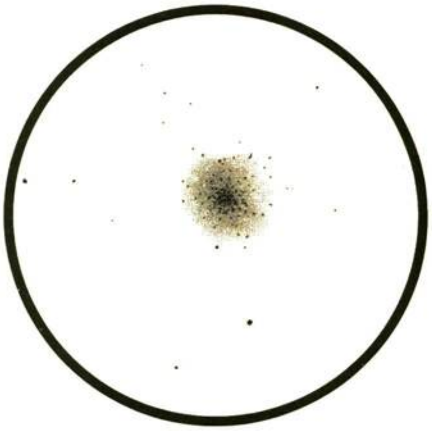
M-13

**8-inch f/10
SCT
100x**



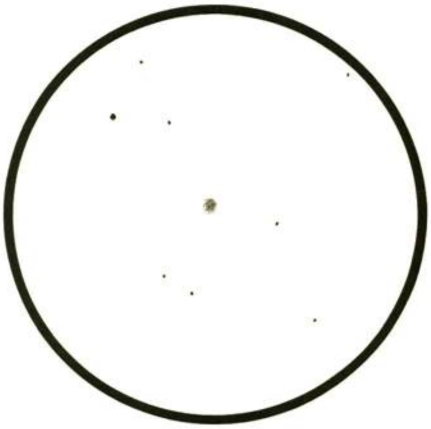
M-92

**8-inch f/10
SCT
100x**



NGC-6210

**17.5-inch
f/4.5 reflector
71x**

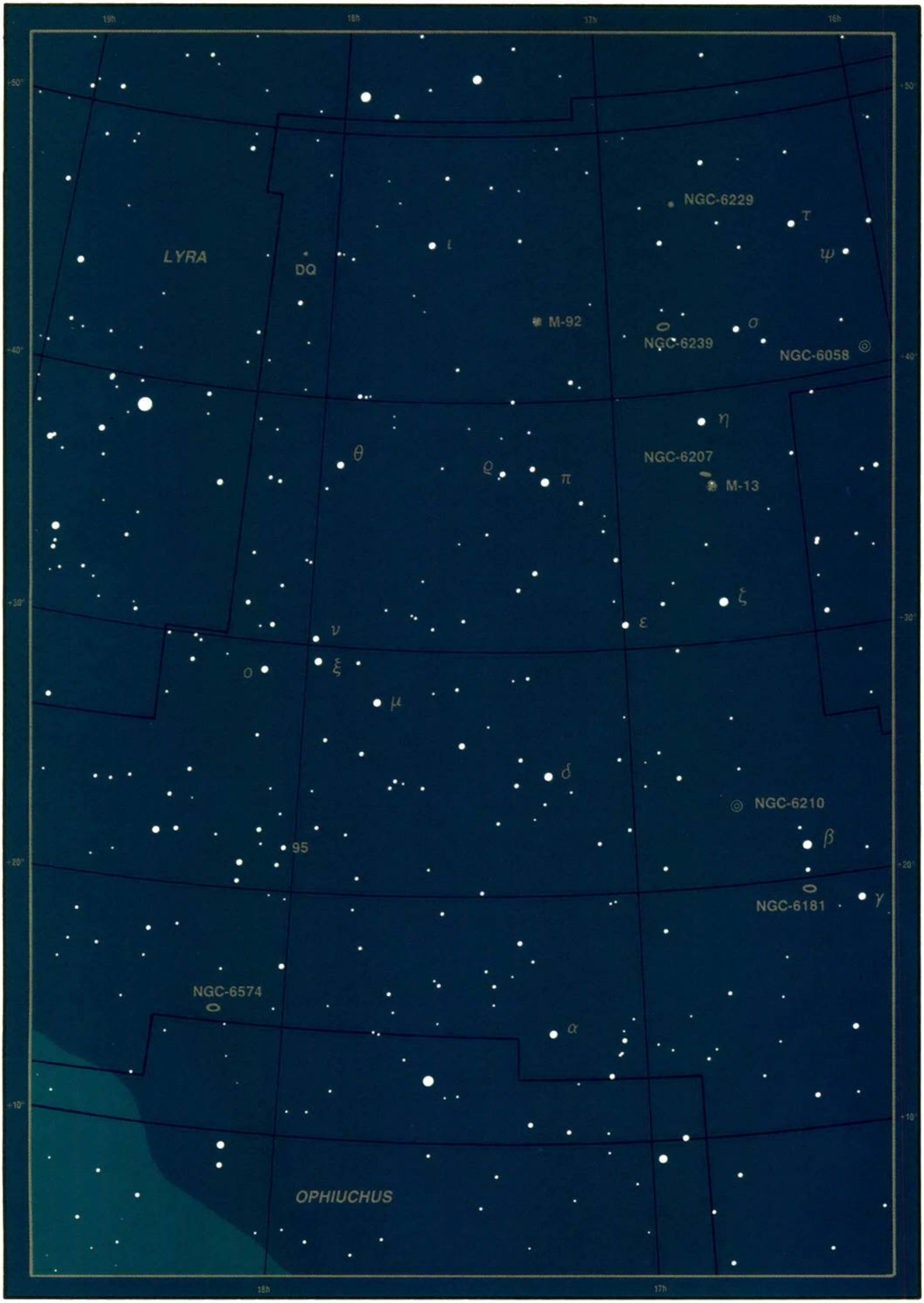


Sketches by David J. Eicher

Object	M#	Type	R.A. (2000)	Dec.	Mag.	Size/Sep./Per.	H
NGC-6058		■	16h 04.4m	+40°41′	13.3p	23″	
NGC-6052		§	16h 05.2m	+20°32′	13.0	1.0′x0.7′	Sc
IC 4593		■	16h 12.2m	+12°04′	10.9p	12″	
NGC-6106		§	16h 18.8m	+ 7°25′	12.2	2.6′x1.5′	Sb$^+$
NGC-6181		§	16h 32.3m	+19°50′	11.9	2.6′x1.3′	Sc
NGC-6205	M-13	●	16h 41.7m	+36°28′	5.9	16.6′	
NGC-6207		§	16h 43.1m	+36°50′	11.6	3.0′x1.4′	Sc
NGC-6210		■	16h 44.5m	+23°49′	9.3p	14″	
NGC-6229		●	16h 47.0m	+47°32′	9.4	4.5′	
NGC-6239		§B	16h 50.1m	+42°44′	12.3	2.8′x1.3′	Sb
Alpha (α)		SRV	17h 14.6m	+14°23′	3.1↔3.9	90:d	
NGC-6341	M-92	●	17h 17.1m	+43°08′	6.5	11.2′	
NGC-6482		0	17h 51.8m	+23°04′	11.3	2.3′x2.0′	E3pec
95		★^{2}	18h 01.5m	+21°36′	5.0,5.1	6.3″	
DQ		N	18h 07.5m	+45°51′	1.3↔15.6	—	
NGC-6574		§	18h 11.9m	+14°59′	12.0	1.4′x1.1′	S:

★^{2}	*Double Star*
SRV	*Semi-regular Variable*
N	*Nova*
●	*Globular Star Cluster*
■	*Planetary Nebula*
§	*Spiral Galaxy*
§B	*Barred Spiral Galaxy*
0	*Elliptical Galaxy*

H = Hubble classification type for galaxies


19h
18h
17h
16h
+50°
+40°
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LYRA
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NGC-6229
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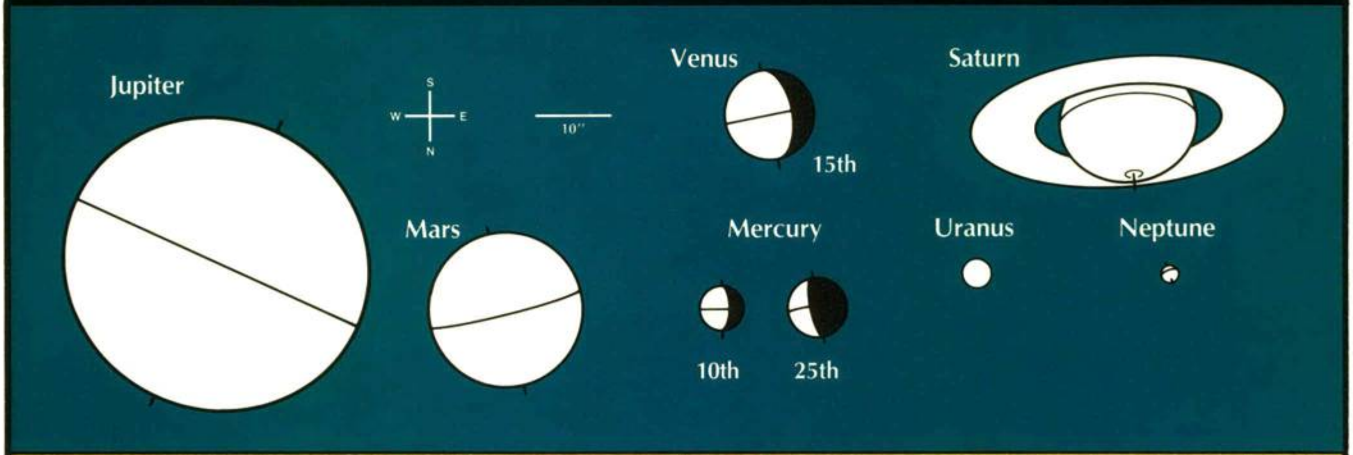
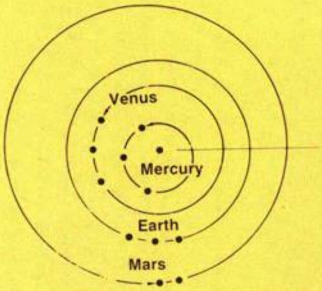
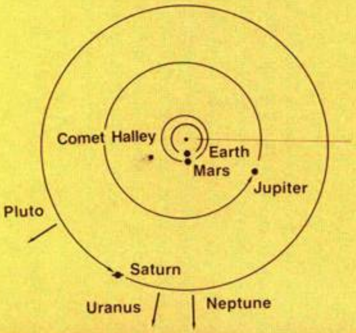
NGC-6210
β
95
NGC-6181
γ
NGC-6574
α
OPHIUCHUS
18h
17h

Planetary Data **June 1986**


Jupiter
S
W
E
N
10″
Venus
15th
Saturn
Mars
Mercury
10th
25th
Uranus
Neptune

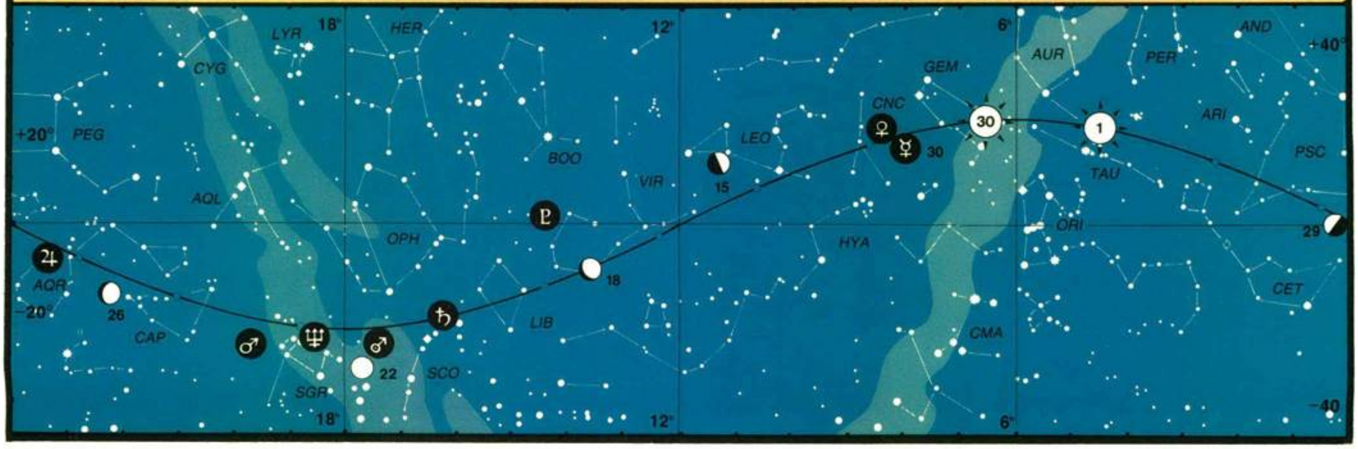
	Date	Mag.	Angular Size	% Illum.	Distance (AU) from:		Longitude:		R.A. (2000.0)	Dec.
					Earth	Sun	Heliocentric	Ecliptic		
Sun	1	−26.7	31.6′	—	1.01	—	—	70°13.7′	4h 35.2m	22°00.8′
	15	−26.7	31.6′	—	1.02	—	—	83°37.5′	5h 33.0m	23°17.9′
	30	−26.7	31.5′	—	1.02	—	—	97°56.0′	6h 35.3m	23°11.7′
Mercury	1	−1.3	5.4″	90%	1.25	0.32	117°12.0′	81°01.4′	5h 20.8m	24°48.6′
	15	−0.1	6.6″	60%	1.02	0.39	184°45.3′	106°03.5′	7h 11.0m	24°19.7′
	30	0.8	8.8″	32%	0.76	0.46	233°28.6′	122°50.5′	8h 20.7m	19°07.2′
Venus	1	−4.0	12.6″	83%	1.34	0.72	151°27.6′	102°40.3′	6h 55.8m	24°36.2′
	15	−4.0	13.5″	79%	1.24	0.72	174°11.4′	119°15.6′	8h 07.4m	22°13.1′
	30	−4.0	14.7″	74%	1.13	0.72	198°26.6′	136°46.9′	9h 19.3m	17°33.4′
Mars	10	−1.9	18.7″	96%	0.50	1.45	269°58.2′	293°14.5′	19h 43.2m	−24°53.1′
	20	−2.1	20.6″	98%	0.46	1.44	275°44.3′	292°29.8′	19h 40.5m	−25°44.5′
Jupiter	15	−2.4	40.6″	99%	4.86	5.00	339°55.0′	351°48.0′	23h 31.8m	− 4°18.3′
Saturn	15	0.1	18.3″	100%	9.03	9.99	246°57.6′	245°18.4′	16h 15.0m	−19°13.2′
Uranus	15	5.5	3.9″	100%	18.13	19.15	260°25.1′	260°25.2′	17h 18.3m	−23°11.3′
Neptune	15	7.9	2.3″	100%	29.25	30.24	274°21.8′	274°54.4′	18h 21.3m	−22°14.6′
Pluto	15	13.7	0.1″	100%	29.07	29.72	216°19.3′	215°00.1′	14h 33.1m	2°45.7′


Venus
Mercury
Earth
Mars


Comet Halley
Earth
Mars
Jupiter
Pluto
Saturn
Uranus
Neptune

Moon Data

New Moon............June 7 at 14h00m
First Quarter..........June 15 at 12h00m
Full Moon.............June 22 at 3h42m
Last Quarter............June 29 at 0h53m
New Moon..............July 7 at 4h55m
First Quarter...........July 14 at 20h10m
Apogee: June 7 at 1h55m.....406,562 km.
Perigee: June 21 at 12h49m...357,668 km.


18h
LYR
HER
12h
6h
AUR
AND
+40°
CYG
GEM
PER
CNC
+20°
PEG
LEO
30
1
ARI
PSC
BOO
15
30
TAU
VIR
AQL
ORI
HYA
OPH
29
AQR
−20°
18
CET
26
CAP
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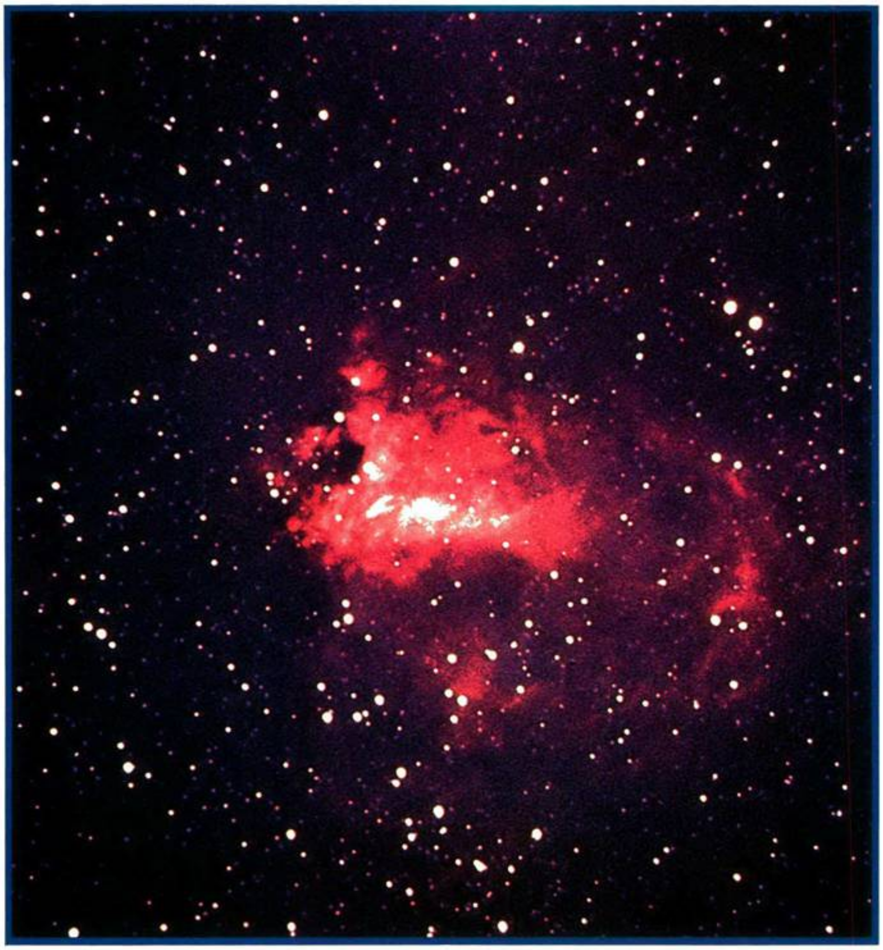
22
SCO
SGR
18h
12h
6h
−40



The Omega Nebula (M-17) is one of the brightest and most easily observed emission nebulae in the summer sky. Its distinctive shape is readily visible in telescopes as small as 3-inches in aperture. This shot was made using a 16-inch f/4.5 reflector, Ektachrome 200 Professional film, and a 20-minute exposure. The resulting negative was copied onto Kodachrome 25 film to improve the color balance. Photo by Jack B. Marling.

Mercury

Mercury reaches greatest angular separation from the Sun (25°) on June 25, but its highest elevation in the evening sky (9.5°) occurs about ten days earlier. From the 10th through the 26th, Mercury will be at least 8° above the west-northwestern horizon some 45 minutes after sunset. As it is one of the year's most prominent displays for this elusive planet, telescope owners should make the most of this chance to see it.

In telescopes, Mercury shows a featureless disk about 7" in diameter. During June, its apparent phase will change from 90% illuminated on the 1st to 30% by the 30th.

Venus

About mid-June, Venus hits peak elevation in the evening sky (18°) around 45 minutes after sunset. Setting about two-and-a-half hours after the Sun, it will remain visible as the "evening star" until early autumn. This month, Venus displays a white, featureless disk about 13" across. The disk is about 75% illuminated and looks distinctly gibbous in your telescope eyepiece.

On the 25th, when Mercury is at greatest eastern elongation, Venus will join with Mercury and the stars Castor and Pollux to form an eye-catching group in the western sky after sunset. The grouping will also be visible, though somewhat looser, for a few days before and after that date.

Earth

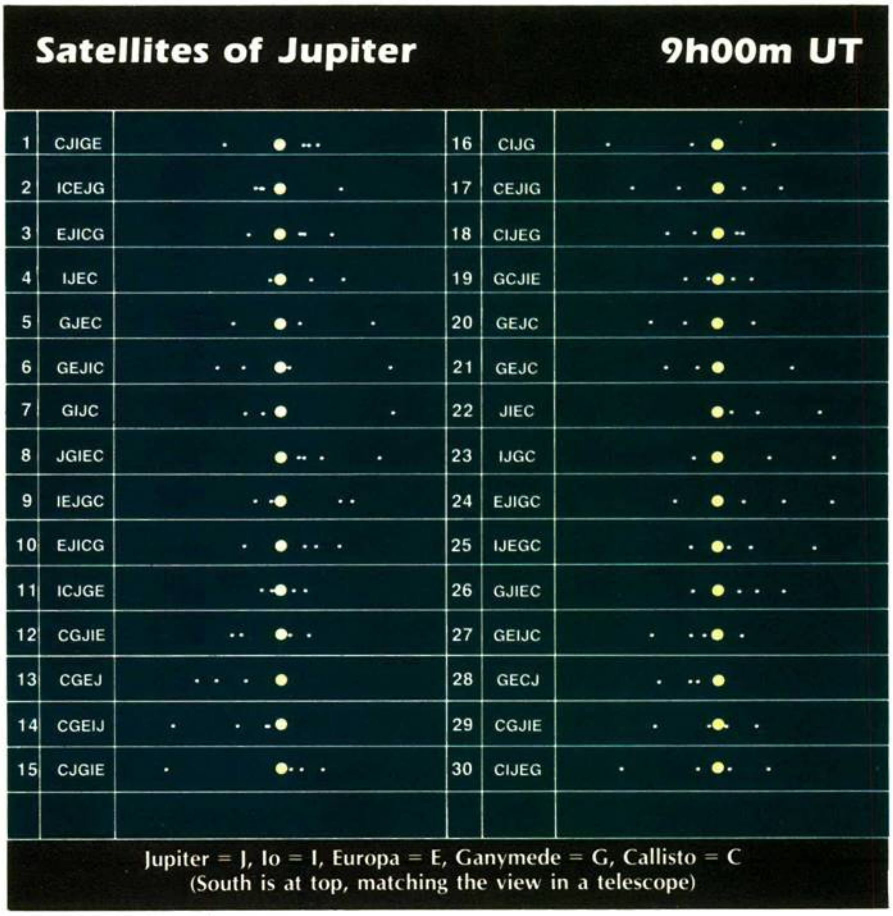
At 16h30m UT on June 21, the Sun reaches its greatest northern declination for the year. This is the June solstice, which marks the beginning of summer in the Northern Hemisphere.

Mars

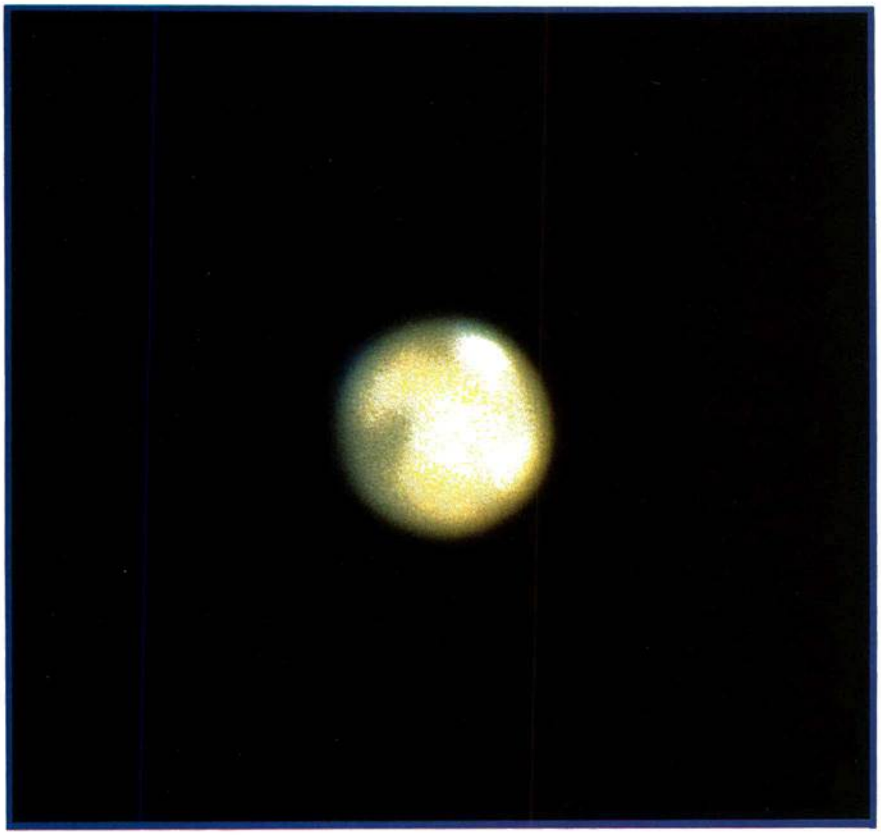
During June, Mars lies to the east of the handle of the Teapot asterism of Sagittarius. (In old astronomy books, this is sometimes referred to as the "Milk Dipper.") Mars' distance from Earth decreases by 18.7 million kilometers this month, making the planet 63.6 million kilometers from us by the 30th. During the same period, its disk grows by 29% — from 17.1" across to 22.1". This means that besides being bright, Mars offers telescope owners a lot to see. This month's "Gazer's Gazette" on page 80 provides further details.

Mars reaches opposition on July 10, so seize every chance you get to observe the Red Planet this summer. After this excep-

Satellites of Jupiter **9h00m UT**



Jupiter = J, Io = I, Europa = E, Ganymede = G, Callisto = C
(South is at top, matching the view in a telescope)



During the summer of 1986, Mars will be an impressive sight in backyard telescopes. It reaches opposition on July 10 when it will shine at magnitude −2.6 and measure 23″ across. Look for the dark maria and the pristine white polar cap. Photo by Don Parker.

Donald R. Thompson wins this month's $100 "Best Astrophoto" award with his lunar photo showing the terminator crossing Sinus Iridium. The prominent crater Plato lies to the right of center.

tional opportunity, you won't see its dusky markings again so easily for another two years.

Minor Planets

1 Ceres (magnitude 8.0) is moving eastward in the hindquarters of Leo. It passes 38′19″ north of 3.3-magnitude Theta (θ) Leonis at 10h14m UT on June 15. About a week later, it passes some 3° north of the pair of galaxies M-65 and M-66. Ceres' positions:

1st: 11h 00m 18s, 18° 30.5′
10th: 11h 08m 42s, 17° 00.5′
20th: 11h 19m 09s, 15° 15.6′
30th: 11h 30m 36s, 13° 26.6′

Ceres sets around 1:30 a.m. local daylight time on the 15th.

2 Pallas (8.8) is moving eastward just north of the head of Hydra. Its positions:

1st: 8h 20m 29s, 6° 01.2′
10th: 8h 38m 39s, 6° 39.8′
20th: 8h 58m 56s, 7° 06.9′
30th: 9h 19m 14s, 7° 19.2′

Pallas sets about 10:30 p.m. local daylight time on the 15th.

3 Juno (10.2) has a retrograde motion in west-central Ophiuchus. Its positions:

1st: 16h 39m 34s, −3° 45.3′
10th: 16h 32m 00s, −3° 29.5′
20th: 16h 24m 10s, −3° 24.7′
30th: 16h 17h 33m, −3° 33.3′

Juno, at opposition on June 1, is visible all night long during the month.

4 Vesta (7.8) has a direct (eastward) motion near the borders of Pisces and Cetus. Its positions:

1st: 0h 11m 44s, −4° 32.1′
10th: 0h 24m 20s, −3° 37.3′
20th: 0h 37m 19s, −2° 45.8′
30th: 0h 49m 05s, −2° 05.5′

Vesta rises around 2:30 a.m. local daylight time on the 15th.

80 Sappho (11.2) is moving retrograde in the tiny Milky Way constellation of Scutum. It is at opposition on June 27. Its positions:

1st: 18h 47m 00s, −11° 41.7′
10th: 18h 41m 25s, −10° 49.1′
20th: 18h 32m 45s, −10° 00.9′
30th: 18h 22m 44s, −9° 25.4′

Sappho rises around 9 p.m. local daylight time on the 15th.

To locate a minor planet, plot its dated positions (given for 0h UT) lightly in pencil on a good star atlas (*Sky Atlas 2000.0*, for example) and sketch a smooth curve linking the points. Then observe the starfield at low magnification and photograph or plot by hand what you see. Check the field a night or two later; the "star" that moved is it. (All minor planet coordinates are for the epoch 2000.0.)

Jupiter

As morning twilight begins, Jupiter is high in the south-southeast and will cross the meridian around sunrise. It makes a striking and enjoyable target for your telescope. Though discerning most details in its cloud belts calls for a telescope with an aperture of 10 inches or more, those who observe with smaller scopes are seldom disappointed by the view.

The trick to getting the most out of Jupiter with a small scope lies in observing the planet at every opportunity when the atmosphere is steady. You'll find that magnifications of 100x to 150x work best on most nights. Besides practice, many long-time observers recommend colored filters to increase the contrast of Jupiter's subtly-colored features. Try using a light yellow or light blue photographic filter and observe how the belts change their relative contrast as you switch from one filter to the other.

Saturn

Being farther from the Sun and less internally active than Jupiter, Saturn's atmosphere displays far fewer details than Jupiter's does. You'll find a large scope and filters essential for viewing Saturn's belts and zones.

If the seeing is very steady, use high magnification and try to spot Encke's Division in the A ring, the outermost of the visible bright rings. (Don't be misled by the broad and easy Cassini Division that separates the A ring from the B ring!) Encke's Division lies about one-fifth of the way in from the A ring's outer edge and is notoriously hard to spot. Your best chance for success lies in searching the *ansae*, the parts of the ring that lie farthest from the ball of Saturn.

Uranus

Uranus reaches opposition on June 11, when it lies 2.72 billion kilometers from Earth. Locate the planet by centering 3.3-magnitude Theta (θ) Ophiuchi in a low-magnification eyepiece and scanning almost 2° north. Uranus has a 3.9″, sixth-magnitude disk that will appear distinctly bluish green in all but the smallest telescopes.

If you have a scope 8 inches or larger, search for Titania, Uranus' brightest moon. Fourteenth-magnitude Titania circles Uranus once every 8d 17h. It lies north of the planet on the 2nd (18h UT), 11th (12h), 20th (6h), and 29th (1h). The satellite lies 33″ from Uranus.

Neptune

Neptune also reaches opposition this month (June 26) when it will be 4.38 billion kilometers away — over 1.5 times farther than Uranus. The light from Neptune left the planet just over four hours before you see it!

Look for the planet by placing the Trifid Nebula (M-20) in the center of your field of view using a low-magnification eyepiece. Sweep about half a degree north and scan 17 minutes of right ascension east (or wait 17 minutes with the telescope's clock drive turned off). Neptune is dimmer and smaller than Uranus; its brightness is 7.9 magnitude and its blue-grayish disk measures 2.3″ across.

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10" Model 2120/LX3

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From the leading edge of telescope technology, Meade brings you the new Model 2045/LX3 4" Schmidt-Cassegrain. With features so advanced, they're unavailable on *any* other ultra-portable telescope.

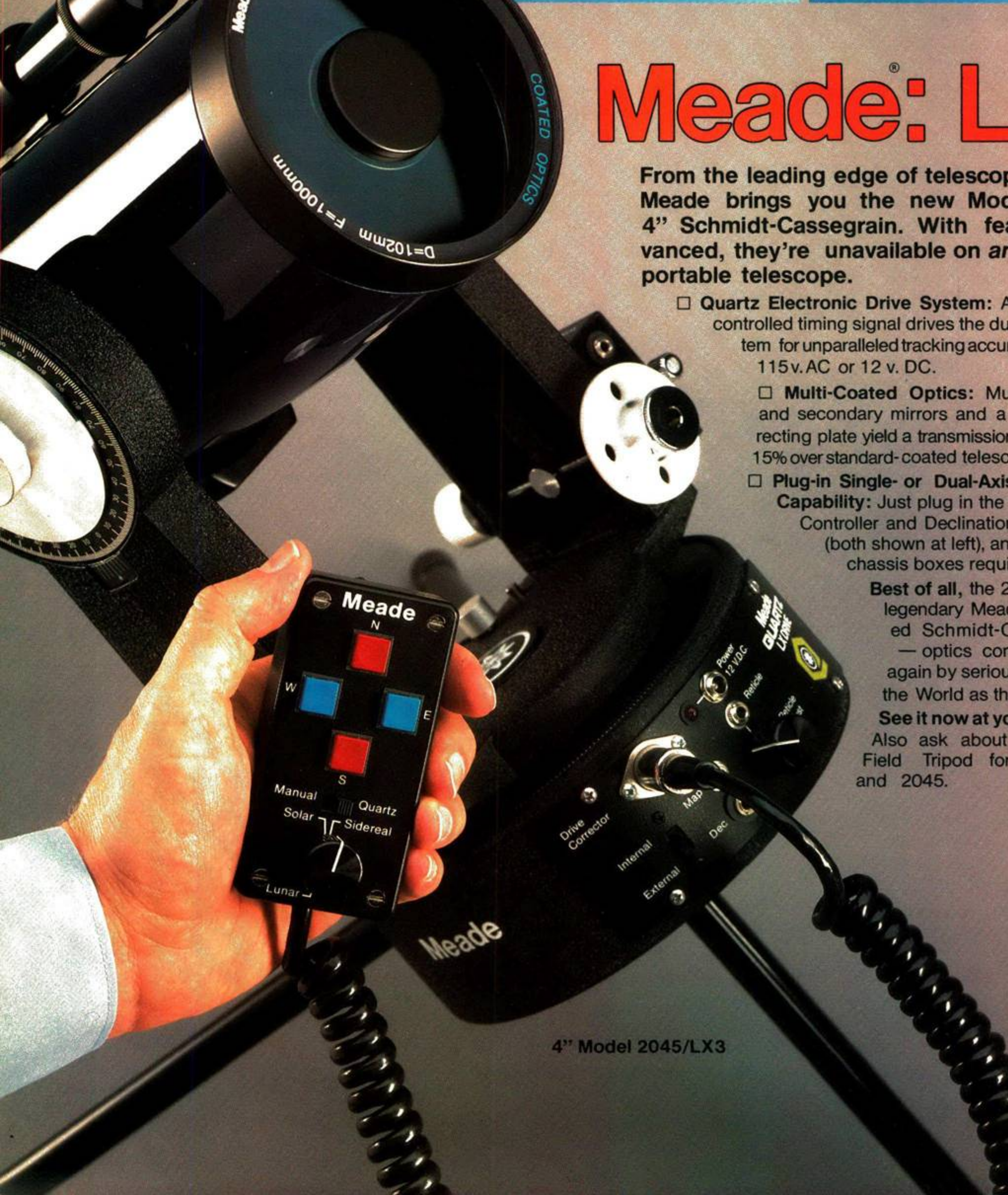
☐ **Quartz Electronic Drive System:** An internal quartz-controlled timing signal drives the dual-motor gear system for unparalleled tracking accuracy. Operates from 115 v. AC or 12 v. DC.

☐ **Multi-Coated Optics:** Multi-coated primary and secondary mirrors and a multi-coated correcting plate yield a transmission increase of about 15% over standard-coated telescopes.

☐ **Plug-in Single- or Dual-Axis Drive Corrector Capability:** Just plug in the optional Dual-Axis Controller and Declination Motor Assembly (both shown at left), and use. No external chassis boxes required!

Best of all, the 2045/LX3 includes legendary Meade diffraction-limited Schmidt-Cassegrain optics — optics confirmed again and again by serious amateurs around the World as the finest available.

See it now at your Meade dealer. Also ask about the new Meade Field Tripod for the 2045/LX3 and 2045.


Meade
SCHMIDT CASSEGRAIN f/10
COATED OPTICS
D=102mm F=1000mm
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N
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Manual
Quartz
Solar
Sidereal
Lunar
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Quartz
LX3
Power 12 V.D.C.
Reticle
Drive Corrector
Internal
External
Map
Dec
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4" Model 2045/LX3

New Meade GEM Series 8" and 10" Schmidt-Cassegrains: The Best—at more affordable prices.

Models 2080/GEM and 2120/GEM (with **G**erman-type **E**quatorial **M**ounts) include the same optical tube assemblies as Meade fork-mounted Schmidt-Cassegrains, but at more affordable price levels. Consider these *standard* features:

German-type Equatorial Mounts with Dual Worm-Gear Controls: Large, stable mountings with easy-to-reach controls for smooth, effortless tracking, yet which transport readily for use in the field. Internal polarscopes are included for precise polar alignment.

years ahead. Again.

Series 4000 Super Plössl 26mm (a $120 eyepiece): For exquisite telescope images at 77X (2080/GEM) or 96X (2120/GEM).

Low-Vibration Field Tripods: Including a heavy-duty hardwood tripod on the 2080/GEM, and rigid all-metal tripod on the 2120/GEM, both tripods height-adjustable.

High Transmission (MgF_2) Coatings on the Correcting Plates: Coatings which increase main-telescope transmission about 10%. The optional Multi-Coated/Silvered Optics Group increases transmission about 23%.

8 x 50mm Viewfinders: Yield viewfinder images almost 3 times as bright as the 6 x 30mm finders included with other German-mounted Schmidt-Cassegrains.

OPTIONAL FEATURES

#784 Quartz Motor Drive: DC powered, for fully automatic sidereal tracking and push-button R.A. drive correction.

#3000 Computer Control System: Includes pulse motors and optical encoders on both telescope axes for automatic slewing and object-location from an extensive pre-programmed library of deep-space objects. See the Meade General Catalog for details on this important option.

New 1986 Meade General Catalog 86-C: $3.00
Includes detailed information on Meade astronomical telescopes, spotting scopes, and accessories. Send $3.00 for your copy.

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For your nearest Meade dealer location, or for free telescope assistance, call Meade Instruments **toll-free** from anywhere in the continental U.S.A., except Calif.:

1-800-854-7485

From all other areas, including California, call direct: **(714) 556-2291**

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#3000 COMPUTER CONTROL SYSTEM
SUPER PLÖSSL

Super Plössl 26mm Eyepiece is included with each 2080/GEM & 2120/GEM.

Meade Instruments Corporation
1675 Toronto Way, Costa Mesa, Calif. 92626 ☐ (714) 556-2291

The telescope people look up to.

Is Celestron's Super C8 Plus an impossibly high standard to achieve? For other manufacturers apparently.

Making the world's finest optics requires a lot of nighttime sky. More than twenty year's worth, fifteen of which have been spent perfecting our C8. And when you spend that much time building, testing and refining a product, you set a very high standard indeed.

Consider our optics. They're engineered to a tolerance of 1/10 wave, about a millionth of an inch, for true "diffraction limited" optical performance. Our exclusive "matching" procedure puts corrector plate and mirrors in a special fixture to ensure precise optical alignment. Through laser testing we detect any minute flaws, then correct them.

These are slow processes, designed to meet our criteria for telescope performance, not sales performance.

Next, consider what you get in every Super C8 Plus. A telescope with 8-inch diameter, 2000mm focal length and F/10 focal ratio. In short, a telescope that provides the ideal balance between portability and large-diameter light-gathering ability.

C8 Astrophotographs: M-17, Omega Nebula; M-13, Globular Cluster; NGC-253.

Then there are the features that come with every Super C8 Plus: A stable Swing-through Fork Mount and an ultra-precise Byers Worm Gear Drive. Full setting circles and slow motion controls for both axes. And our Deluxe Latitude Adjuster.

An 8X50 polar alignment finderscope also comes standard, as do two oculars: a multicoated Plossl for wide field 77X magnification and a fully-coated Orthoscopic for 286X magnification.

There is a telescope, however, equal to the Super C8 Plus. Our own Super Polaris C8. It offers the same optics, the same performance. The Super Polaris Mount, which features a precise built-in polar alignment telescope, can be used with our optional Sky Sensor computer control system.

Now, if you'd rather look through a Super C8 Plus or SP-C8 than look up to one, focus on the Celestron dealer nearest you.

Just because some manufacturers can't raise their standards is no reason for you to lower yours.

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